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Ergonomic Impact of Glove Use in a Coating Removal Task

By

Ian C. Rybczynski
B.S. (Arizona State University) 1995

THESIS

Submitted in partial satisfaction of the requirements for the degree of

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ABSTRACT

Workers who are in maintenance and repair occupations are routinely exposed to several musculoskeletal disorder risk factors. The purpose of this study was to investigate the effects of glove use during a coating removal task, which is a common maintenance and repair task. Nine healthy subjects (5 male and 4 female) participated in this study. The subjects removed identical painted sections using either a metal finishing (nylon) pad or a plastic scraper, while wearing one of thirteen glove conditions. The order of the glove conditions was randomized for each subject. Force exertions were monitored along with EMG readings from the finger flexors, finger extensors, biceps, and triceps. The results showed that there were significant increases in force outputs and muscle activities when using gloves as compared to a barehanded condition. There was some evidence that indicated glove material and glove thickness are important characteristics in these observations. These findings may have implications for a worker's musculoskeletal disorders risk and for glove selection guidelines in industry.

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I. Introduction

Coating removal tasks are very common in repair and restoration type work. The removal of paints, sealants, and other types of coatings is usually necessary before a new coating can be applied. Generally, the base material or substrate that a coating is applied to is a metal or wood. For example, a common coating (i.e. paint) removal task where wood is the substrate is home restoration. Often, the older layer of paint is removed in order to improve the adhesion and the appearance of the new layer of paint. Similar paint removal tasks are performed on metallic structures like bridges, vehicles and aircraft. Further, in vehicle and aircraft maintenance/repair, coating removal tasks can be more diverse. In addition to paints, coatings such as sealants, adhesives, spray-foams, and other similar substances need to be removed and replaced.

Chemical solvents are often used to assist workers during certain coating removal tasks. The solvents are used to weaken the coating's adhesion to the substrate, which then makes the removal process easier. Once the solvent has been applied to the coating, manual removal with non-powered hand tools is often done to ensure the coating is completely removed. However, chemical solvents usually present health risks to the workers, so personal protective equipment (PPE) is needed to reduce the chemical contact and absorption hazards. Although the PPE used to protect the worker's body varies depending on the nature of the task, gloves are almost always required when good industrial hygiene practices are employed. This means that the worker must use a non-powered hand tool while wearing gloves, which may affect the MSD risks the worker is subjected to when conducting this task.

II. Background

2.1. Musculoskeletal Disorders

Musculoskeletal disorders (MSDs), cumulative trauma disorders (CTDs), or repetitive trauma disorders (RTDs) are names commonly used for occupationally related illnesses of the soft tissues of the upper extremities. Although the name used for this type of illness is not always the same, current statistics indicate that the US working population is getting more and more familiar with these upper extremity disorders. Since 1980, the number of workers suffering from some type of upper extremity disorder has been on the rise and in 1994 alone 332,000 workers or 60% of all newly reported occupational illnesses were classified as upper extremity disorders "associated with repetitive trauma" (Silverstein 1997).

Statistics like the ones presented above may lead one to believe that occupationally related upper extremity MSDs are a new problem, but that is not the case. Actually, a link between an individual's occupation and upper extremity MSDs has been documented for centuries. Violin player's cramp, telegraphist's cramp, and writer's cramp are just a few of the first musculoskeletal injuries/diseases that were diagnosed as being occupationally related problems in the early 1800s (Melhorn 1998). Although the cause of theses diseases, one's occupation, has been clear for all of this time, prevention of these diseases has been a very difficult task.

Many researchers have been working on gaining a better understanding of upper-extremity MSDs; however, there are still many questions that need to be answered. This is best illustrated by the fact that upper-extremity MSDs continue to plague the workforce. Previous efforts have helped identify some of the major risk

factors for upper-extremity disorders and these factors are repetition, awkward postures, forceful exertions, vibration, and task duration (NRC 2001). Unfortunately, the exact dose-response relationships between each risk factor and MSD development has been very difficult to understand. Since it is often impossible to completely eliminate worker exposures to all of these risk factors, a better understanding of this dose-response relationship is essential.

Non-powered hand tool use is a good example of a category of work where a worker is exposed to at least one, if not almost all, of the major risk factors for MSDs. Usually, the physical nature of hand tool use alone will expose the worker to some type of forceful exertion. Additionally, repetition, long duration and awkward postures may also be present in the task depending on the type of work and the work environment. Workers who are in maintenance and repair occupations are a good example of a class of workers who routinely have tasks where exposure to all four of these risk factors is common.

2.2.1. MSD Risk Factors and Glove Use

A key to developing dose-response relationships for MSDs is defining the level of exposure for a worker. Although this may sound like a simple task, it can become very complicated. What may seem to be only a subtle difference between two workers could have an impact on their actual exposure to a MSD risk factor. One such subtle difference may be glove use.

The exact effect that glove use has on a worker appears to be complicated, but it is centered on force requirement differences. Many studies have shown that gloves reduce the grasping force when compared to a barehanded condition (Swain, 1970;

Cochran, 1986; Sudhaker, 1988). These studies indicated that higher levels of muscle activation were necessary when wearing gloves because the user's maximum grip force was lower than the no glove (barehanded) condition. Thus, it seems that gloves will have a negative effect on worker performance; however, some studies have also found positive effects when gloves are worn.

An investigation by Riley et al. (1985) found that gloved workers were able to generate higher pull forces and torques when wearing gloves after the frictional effects were negated. Another study conducted by Mital et al. (1994) found that gloved workers were able to generate higher maximum torques with screwdrivers and wrenches when wearing gloves. These two studies both concluded that workers were able to exert higher maximum forces when wearing gloves.

The findings by Mital and Riley suggest that gloves may have a positive effect on worker performance. Since many repair and maintenance tasks call for forceful exertions, it would seem that workers could use higher force outputs to their advantage. However, a possible problem with this logic is Mital and Riley only evaluated maximum efforts. It is not clear what happens at sub-maximal workloads. Ideally, workers could use the increased force outputs to their advantage when working on tasks that require sub-maximal exertions. Theoretically, this would mean that gloved workers could generate the necessary force levels for a task at lower muscles activation levels when compared to a barehanded situation.

To further complicate the previous findings, Buhman (2000) has suggested that maximal grip findings are not relevant to sub-maximal grasps. Through a series of experiments, Buhman provided some evidence that the neuro-muscular control

mechanisms for maximal exertions were not the same as the ones used for sub-maximal grasping exertions.

Explaining why the differences in force output occur when gloves are worn has also been difficult. Cochran (1986) theorized that the reasons are "interference of the glove in closing the hand around objects, the possible decreased friction between the glove and object, and the interference of the glove in tactile feedback". There does seem to be a logical problem with the decreased friction portion of this explanation and Mital's (1994) increased torque findings, though. It would seem if both frictional and grip forces decreased then torque production should also decrease because grip 'slippage' could possibly occur before the maximum torque was reached. Although grip slippage seems less likely as the weak link for maximum torque production with most wrenches, it does seem that grip force would be critical for maximum torque outputs with screwdrivers. Shih (2001) did show that the frictional coefficient for latex surgical gloves was lower than it was for barehanded conditions (and Mital also found that latex gloves were the only glove that didn't improve torque outputs), but most of the thicker chemical gloves have better frictional characteristics than surgical gloves. Additionally, Riley's (1985) findings of higher torques were found after negating frictional effects. Thus, it seems that the other portions of the explanation offered by Cochran may be more relevant to what is actually occurring.

There is some evidence supporting Cochran's statement that tactile feedback is an important factor. Researchers have found evidence that gloves interfere with a person's sense of touch, usually referred to as haptic input (Nelson 1995 and Phillips 1997). Haptic input is likely important for normal motor performance; in fact, one

study showed that when the fingers were completely anesthetized, subject grip force production did not respond appropriately for a series pulling tasks (Johansson 1992). Although gloves obviously do not entirely eliminate the hand's ability to receive haptic input, it is possible that gloves hinder this feedback enough to have some effect on motor performance. One study investigated this question by examining grip forces for subjects holding identically shaped objects of different masses (Shih 2001). This study revealed that the subjects increased their grip forces when gloves were worn and concluded that this increase in grip forces were at least partially due to a loss in haptic sensitivity.

The first part of Cochran's explanation is somewhat vague, but it most likely refers to a mechanical interference that is caused by the gloves presence on a person's hand. Often this interference has been attributed to a reduction in the inter-digit distance and a reduction in the range of motion (Buhman 2000). Assuming this is also what Cochran was referring to, there has been some research on how glove thickness alters force outputs. Mital (1994) stated that thicker gloves were necessary in order to have a torque enhancement effect. Another study found that thicker cotton gloves allowed for higher maximum torque production when using handwheels (Y. Shih 1997). Conversely, Shih (2001) found that glove thickness was not strongly related to pinch grip force, and Tsaousidis (1998) found that gloves did not increase maximum torque production. Thus, there is some evidence that glove thickness will alter force outputs, but it is not conclusive.

If wearing gloves increases a workers muscular effort, even small increases may be very important for highly repetitive tasks that are performed for long

durations. Muscle activation level is important to muscle fatigue times especially at the lower activation levels (Lieber 1992). The amount of time a muscle can work at a particular activation level or the muscle's endurance time has been shown to decrease in a parabolic fashion. This parabolic decrease is greatest for the activation levels below approximately 35% of a maximum voluntary contraction (MVC) for that muscle. To experience this rapid decrease in endurance time, activation levels must also be above a minimum threshold (7 - 15 % MVC). Therefore, when working above this minimum threshold, but below the portion of the curve where the parabolic decrease begins to flatten out (i.e. approximately 35% MVC), even small increases (1 - 5% MVC) in activation level result in much larger decreases in endurance times. Since the fatiguing of the smaller muscles is believed to contribute to the development of upper extremity MSDs, it is important to be aware of what factors can contribute to even small increases in muscles activation levels when performing a highly-repetitive, long-duration task.

2.2. Glove Use for Coating Removal Tasks

Workers wear gloves to protect themselves from physical hazards, chemical hazards, and combinations of both hazards. Since there are numerous types of physical and chemical hazards present in an occupational setting, there are also many different types of gloves available to neutralize these dangers. One common task that presents both chemical and physical hazards to the worker is a coating removal task. As discussed above, coating removal tasks are very common to repair and maintenance occupations because it is often necessary to remove some type of coating (e.g., paint, sealant, spray-foam, etc.) from either a metallic (vehicles, aircraft,

etc.) or a wood (homes, furniture, etc.) surface. The removal tool being used along with the surface that is being worked on can be physical dangers for workers. Chemical hazards are often also present because the worker usually pre-treats the coating with a chemical solvent of some sort to help with its removal. Additionally, the coating or even the surface may contain chemical hazards from fuel or other chemicals it routinely comes in contact with and has absorbed. Since a coating removal task can present a wide variety of chemical hazards with some physical hazards, it is obviously a task where many different glove types can be used.

Selecting the proper gloves to avoid a physical hazard(s) is usually a simple problem, but evaluating gloves for chemical hazard(s) protection is much more complicated. Chemically resistant gloves are usually made from latex, nitrile, butyl, neoprene, polyvinyl chlorine (PVC), ethylene vinyl alcohol (EVOH), or combinations of these materials. Each material provides a different degree of chemical resistance to a specific chemical hazard. Latex and nitrile gloves are possible choices for scraping tasks because they are low in cost, provide good protection from cuts and abrasions, and provide some protection from chemical hazards. Butyl gloves are also a possible choice because they not only provide protection from cuts and abrasions, but they typically provide better chemical resistance than both latex and nitrile gloves. However, EVOH gloves are superior to all three of these glove types in terms of chemical resistance. This superiority in chemical resistance is shown in Table 1, which lists the time (breakthrough time) it takes for common coating removal solvents to permeate the four different glove materials discussed above.

Table 1. Common solvent breakthrough times for four different glove materials

Chemical	Latex Gloves	Nitrile Gloves	Butyl Gloves	EVOH Gloves
Acetone	P (4 min)	P (3 min)	G (367 min)	E (>24 h)
Methyl Ethyl Ketone	P (1 min)	P (6 min)	G (116 min)	E (>24 h)
Methylene Chloride	P (<1 min)	P (4 min)	P (10 m)	E (>24 h)
Toluene	P (<1 min)	P (26 min)	P (<15 min)	E (>24 h)
Xylene	P (<1 min)	P (41 min)	P (9 min)	E (>24 h)

Note: Data presented as a generic glove rating for the glove type (E = Excellent, G = Good, P = Poor) followed by measured breakthrough times in parentheses. Data presented is from Forsberg (1999) and 4H (1996).

The table above clearly illustrates that the EVOH gloves are much better suited for the chemical hazards present, but the problem with these gloves is they provide very poor protection to the physical hazards present in a coating removal task. Additionally, EVOH gloves are usually considered very poor fitting gloves. The poor fit (as shown in Figures 1-3) of these gloves is mostly due to manufacturing limitations with the material itself. EVOH gloves are typically made by cutting front and back sides of the glove from flat sheets of EVOH material and then the edges of the two sides are simply sealed together to form the glove. To compensate for lack of a proper fit as well as poor protection from physical hazards, it is common for workers to wear a glove that provides protection to the physical hazards over the EVOH glove.

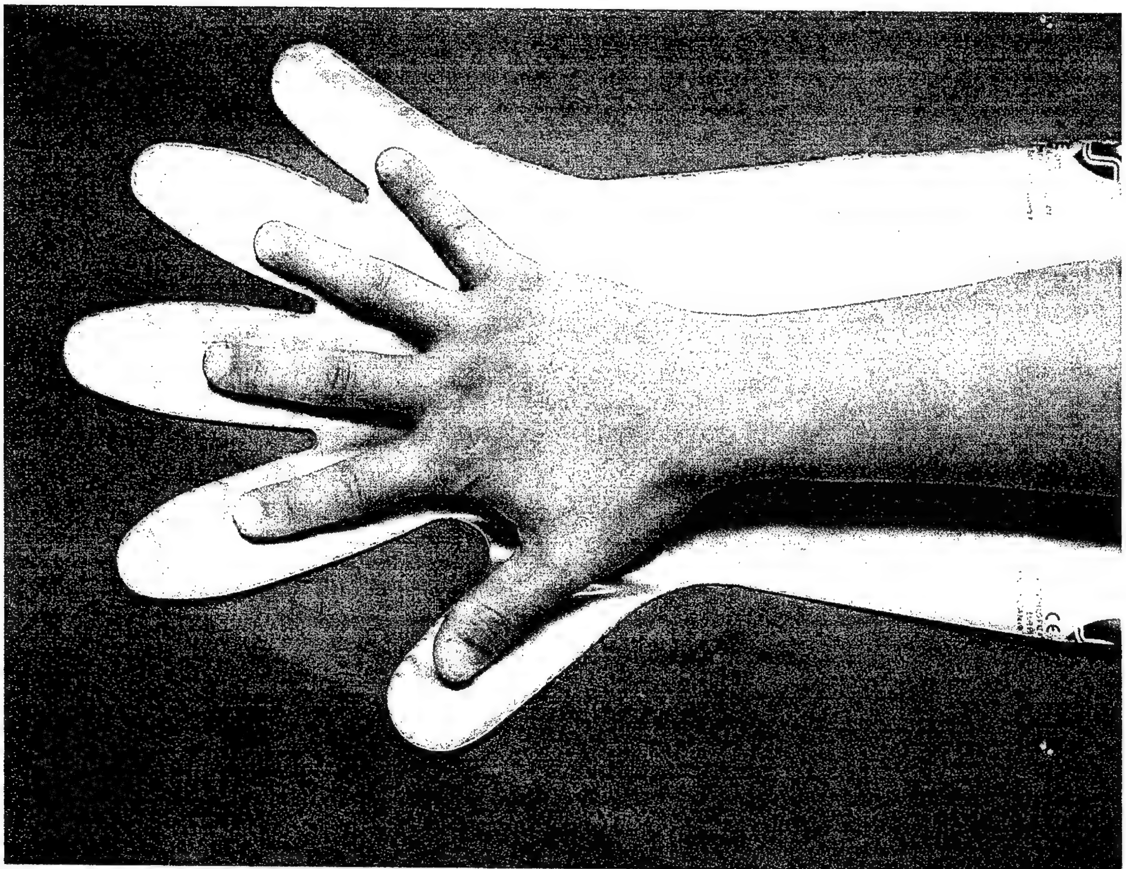

Figure 1. Subject (8) hand overlaying a size 9 (medium) Silver Shield® Glove
Note: Subject's hand width is 8.3 cm and length is 17.5 cm. The subject wears a size 9 glove and he felt that the size 9 Silver Shield ™ glove provided the best fit.

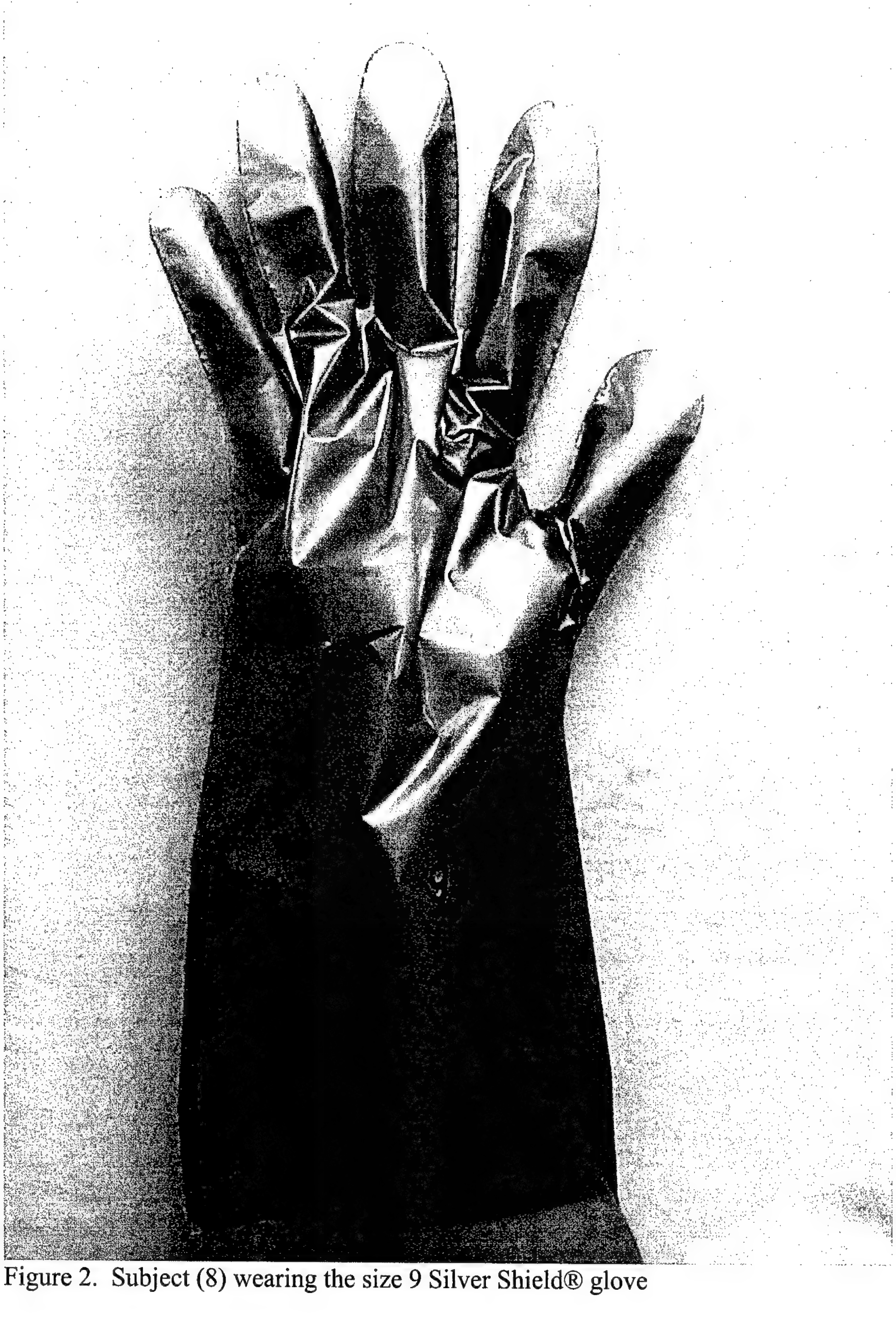

Figure 2. Subject (8) wearing the size 9 Silver Shield® glove

Figure 3. Subject (8) wearing a thin nitrile glove over size 9 Silver Shield®

III. Objective

A coating removal task is a good example of highly repetitive task, which requires a low physical exertion. This task was also chosen because it is a common task for workers in maintenance and repair occupations. This project has been designed to generate a better understanding of how gloves influence worker physical requirements when performing a coating removal task. Although this experiment focused on only one type of task, the information gained will help improve the understanding of how glove use alters MSD risk for workers that must wear gloves. The data collected should help identify if and how gloves affect grip forces and exertions when performing a task that requires an exertion much lower than a maximal exertion. Information will be gathered on how glove thickness, glove material, and the use of chemically resistant under-gloves affect a worker.

3.1 Hypothesis

The null hypothesis is glove thickness and glove material do not affect the applied removal forces or the muscle activation levels in a coating removal task.

IV. Methods

4.1. Subjects

Nine healthy subjects (5 male and 4 female) volunteered to participate in this study. All subjects were screened with regard to any current or previous musculoskeletal disorders, especially for the wrist and arm. All subjects reported that

they did not have or have had any MSD problems. Descriptive statistics on key anthropometric variables for the subjects are presented in Table 2. The subjects were also screened for known latex allergies. All subjects reported that they did not have any allergy concerns and none of the subjects developed skin dermatitis during or after the collection of the experimental data. Finally, all subjects were provided information concerning human subject rights and they signed subject informed consent forms.

Table 2. Subject anthropometrical data

Variable	Average	Std. Dev.	Minimum	Maximum
Age (yrs)	26.6	4.0	21	32
Height (cm)	175.0	11.0	160.0	198.1
Weight (kg)	77.8	21.9	52.2	125.0
Hand Width (cm)	8.0	0.7	6.7	8.9
Hand Length (cm)	18.4	1.2	16.7	20.3
Lower Arm-Medial (cm)	26.8	2.1	23.6	31.7
Lower Arm-Lateral (cm)	25.3	1.8	22.6	29.0
Upper Arm-Anterior (cm)	28.4	2.7	24.6	31.3
Upper Arm-Posterior (cm)	32.9	3.4	30.7	38.9

4.2. Apparatus

4.2.1. Tool Selection

Two tool types were selected for this project: a *3M* metal finishing (nylon) pad and a 2-inch plastic scraper. These two tool types were chosen because they are two of the tools specified in the United States Air Force regulation governing coating removal tasks (USAF 2001). Six different tool types (abrasive cloth, abrasive paper, metallic wool, nylon mats, wire brushes, and plastic scrapers) are specified in this regulation, but pilot studies indicated that the two chosen tools were very effective in removing the experimental coating and neither tool required excessive forces.

Additionally, the tools were classified as having either a handle interface (plastic scraper and wire brush) or a non-handle interface. One tool from each classification was selected for this experiment.

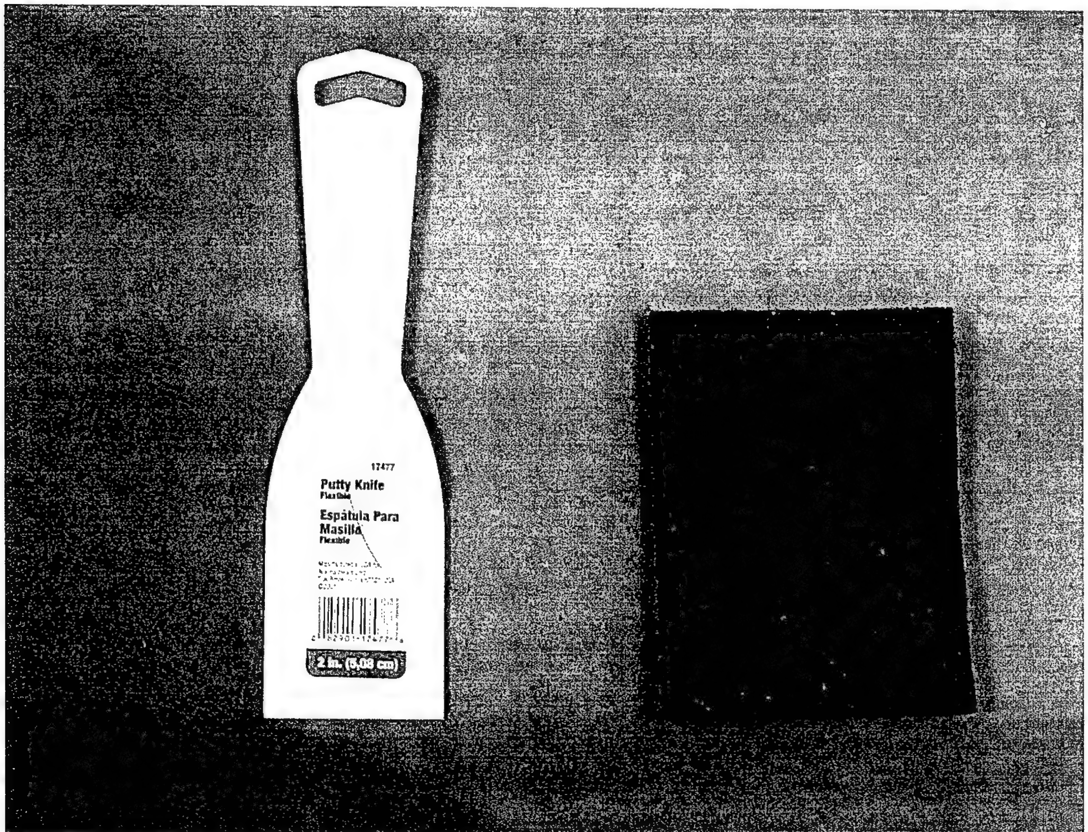

Figure 4. Plastic Scraper and Nylon Pad

The nylon pads purchased for this experiment were 11 cm x 28 cm x 0.5 cm and they were cut into three equal sized sections. This was done, so that the nylon pads could be easily held in one hand. The same nylon pads were cleaned and reused throughout the experiment. The plastic scrapers had a 2-inch (5.1 cm) wide blade and the blade was 2.375 inches (6.0 cm) in length. A new plastic scraper was provided to each subject during data collection.

4.2.2. Substrate-Coating Selection

An important part of this experiment was finding an appropriate substrate-coating combination. The desired characteristics for this combination were the coating should apply easily and uniformly to the substrate and it should be removable with fairly low force requirements. Additionally, chemical solvents should not be required to make the removal process easier. It was desirable to avoid chemical solvents because of the exposure risks for the subjects and the possibility of damaging or altering the surface of the substrate. Many combinations of paints, sealants, and adhesives with different types of metal surfaces were investigated and the most appropriate combination was a stainless steel surface with a coating of latex paint.

4.2.3. Glove Selection

An important goal for this experiment was to evaluate the use of highly chemical resistant glove-liners underneath a more durable over-glove. However, since it is also likely that many similar tasks are conducted without the use of chemical resistant liners, data were collected for the single-layer glove scenarios (i.e. outer-glove only) also. Nitrile gloves were the main material tested as the over-glove. Nitrile gloves were selected because they provide excellent abrasion protection and they are also low in cost, which helps make them a popular choice in many industrial facilities. Four different types of nitrile gloves were used in the experiment: thin (5 mils), average (15 mils), average with "Z" grip, and thick (22 mils).

Two of the other gloves tested in this experiment were a thin latex glove and an average thickness butyl glove. These gloves were tested to examine if there were differences based on glove material. There were two main reasons for only testing

the latex glove at the thin thickness. First, when abrasive hazards are minimal, the thin latex glove (commonly called 'surgical gloves') is the most inexpensive over-glove that is available. Secondly, if abrasive hazards are a problem, it is believed that a thicker nitrile glove would be used rather than a thicker latex glove because nitrile is superior to latex for providing abrasive protection.

Only one thickness (medium) butyl glove was chosen because it is assumed that the variations in butyl over-gloves used in industry would be fairly limited. The main reason butyl gloves are an unlikely glove choice for an over-glove is butyl gloves are approximately 10 times more expensive per pair than equivalent thickness nitrile gloves. However, butyl gloves would be used in some situations because there are some organic solvents that will cause latex and nitrile gloves to break down too quickly. Often, the same chemicals (e.g. fuels and ketones) that cause latex or nitrile gloves to break down will not destroy the butyl glove. Thus, medium thickness butyl glove were selected for this experiment because thick butyl gloves are too expensive to be selected for over-glove purposes and thin (as defined in this experiment) butyl gloves are not manufactured.

The final glove type included in this experiment was a chemically resistant (EVOH) glove liner. A chemically resistant liner was used as the under-glove with each of the gloves already discussed. Although there are some variations of the EVOH liner available, the variations are minimal and the primary style used as an under-glove is the 2.7-mil EVOH liner. Thus, there were 13 glove combinations: (1) barehanded, (2) thin (5 mils) nitrile gloves, (3) thin nitrile gloves with a chemical resistant liner (liner), (4) medium (15 mils) nitrile gloves, (5) medium nitrile gloves

with liner, (6) thick (22 mils) nitrile gloves, (7) thick nitrile gloves with liner, (8) 'Z-grip' medium nitrile gloves, (9) 'Z-grip' medium nitrile gloves with liner, (10) thin latex gloves, (11) thin latex gloves with a liner, (12) medium butyl gloves, and (13) medium butyl gloves with a liner.

Small, medium, and large sizes of all glove and liner types were available for the subjects to use during the experimental trials. Subjects were able to try on all of the glove types and choose the glove that they found the most comfortable. Since more than one glove manufacturer was needed to provide all of the different types of gloves, the small, medium, and large sizes were not exactly the same, but the differences in sizes were minimal. Subjects were able to change sizes for different glove types as necessary; however, almost all of the subjects were satisfied with using one glove-size for all of the glove types.

The subjects reused all of the over-gloves except for the tight-fitting gloves (the thin latex and thin nitrile gloves) during this experiment. The tight-fitting gloves were used for a single experimental condition (i.e. two trials) and then they were thrown away. Each subject had their own EVOH liner that only they used for the duration of the experiment. This was done for subject comfort because the EVOH liner would cause the subjects' hands to perspire during the trials. Finally, the reused over-gloves were kept in two different sets and each set was only used for one of the tool types. This was done incase one of the tools altered the texture of the reused over-gloves during the removal trials.

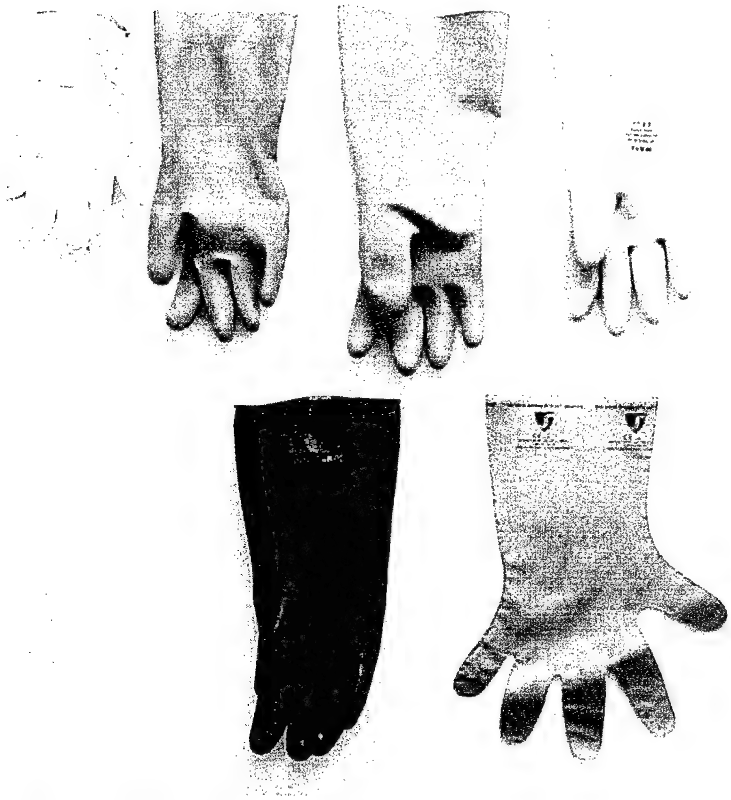

Figure 5. Gloves used in the experiment.
(Clockwise from top-left corner: Thin Nitrile, Medium Nitrile, Thick Nitrile, Silver Shield, Medium Butyl, and Thin Latex.)

4.2.4. Experimental Equipment

A three-dimensional forceplate (Bertec 4060A: Bertec, Worthington, Ohio) was utilized to capture the removal forces for all experimental conditions. To gather EMG data, a bipolar surface electrode EMG system (Biopac MP30: Biopac, Santa Barbara, CA) was used.

4.3. Experimental Design

The experiment was a 2x13 within-subject design and the independent variables were tools (2 levels) and gloves (13 levels; discussed above). One tool type was used with all 13 of the glove conditions on a single day; thus, two days of data

collection were needed for a complete data set on each subject. The dependent variables were average exertion (vector-summation of forces) force, peak exertion force, average normal force, peak normal force, average shear force, peak shear force, average percentage of maximum EMG (%maxEMG) for the static finger flexors, %maxEMG for the static finger extensors, %maxEMG for the dynamic finger flexors, %maxEMG for the dynamic finger extensors, %maxEMG for the dynamic biceps, and %maxEMG for the dynamic triceps.

4.4. Experimental Procedures

The basic process entailed gathering data on each subject while they performed the same coating removal task with different glove and tool combinations. There were three major categories of the data collected during each experimental condition: (1) force data, (2) EMG data, and (3) subjective assessments of the physical exertions.

Eight working surfaces (40 x 60 cm rectangles) were cut from a single piece of stainless steel sheet metal for this project. The dimensions of the working surface were the same as the force plate. This made it easy to secure the working surface to the force plate with packing tape. In order to provide sufficient space for the subjects to perform the removal task without interference from other painted sections, only four painted squares were allowed on each of the working surfaces. Each of the four squares was located in the same relative position from the four corners of the steel surface. Data were collected while the subjects worked on the painted squares along the width (40 cm dimension) of the surface when it was closest to them. The working surface was then turned so that the painted sections were always in this position

during removal trials. A diagram of the surface configuration is included in Appendix A.

The removal motion used by the subjects was well defined. The working surface/forceplate combination was on a countertop, which was approximately three feet high. Subjects were able to place one hand on the countertop for balance and work with their dominant hand. The removal method itself involved locking the elbow at approximately 90 degrees and generating the necessary motion from shoulder flexion/extension. Removal exertions were parallel to the Y-axis (fore-aft) of the force plate. Removal exertions were in one direction only (i.e., positive Y; no back-and-forth motions). Once the subjects finished a single removal exertion, they raised their hands above the working surface and moved their hands back (via shoulder flexion) to prepare for the next exertion. Subjects were asked to perform this removal task at a pace that was appropriate for an 8-hour work shift.

Subjects practiced the coating removal process at least four times prior to data collection. During the practice trials, subjects were asked to develop a pattern for their removal process as well as develop a consistent work pace. Subjects were also asked to be conscious of the method they used to grip each tool, so that they would remember to use the same grip during each of the trials. All trials were video recorded in case subtle changes in work technique occurred; however, the task was simple enough that subjects were very consistent with their removal techniques.

Subjects were asked to remove a 10 cm x 10 cm square that was painted on the sheet metal for each removal trial. The painted squares were sprayed with water prior to the subjects performing the removal process. Each square was sprayed with

water until it was completely saturated. Subjects were asked to wait 60 seconds before starting the removal task. Pilot trials indicated that waiting 60 seconds sufficiently weakened the paint's adhesion to the metal surface. Once weakened, the paint could be removed consistently and completely from the stainless steel surface. A complete data set for each of the experimental condition required the subjects to remove two painted squares from the metal surface.

Figure 6. A subject performing a removal trial with the nylon pad.

In order to get a complete data set for a single tool, 26 painted sections were needed. Eight working surfaces provided this and six additional painted sections, which were used for practice trials. A single removal trial lasted 4 to 10 seconds (depending on the subject and experimental conditions) and required only a low-level physical exertion from the subject. At minimum, subjects had sixty seconds of rest in-between two removal trials for the same experimental condition and the rest time in-between experimental conditions was in the range of 2-5 minutes. Extra time was

needed in-between different experimental conditions to rearrange the working surface and allow the subjects to change gloves. Although all subjects were routinely asked if they needed more rest time throughout data collection, none of the subjects requested extra rest time. Also, no subjects reported feeling fatigued during or after completing an entire experimental session. Subjects usually sat down and rested in-between each trial and the experimental conditions.

As mentioned above, only one tool type was tested during an experimental session. This was done because a single experimental session lasted for approximately 1.5 hours. It was decided that trying to gather data for both tools during one session would make the experimental sessions unnecessarily long and would increase the likelihood of subjects experiencing some fatigue during data collection. This meant that two days of data collection were needed to get a complete data set on each subject. The tool used by the subjects on the first day was randomized and subjects had a minimum of three days rest before data were collected on the other tool.

During the experimental sessions, the glove order used by the subjects was also randomized. All of the glove conditions were assigned a numerical code and subjects drew numbers to determine their glove order. Once a subject completed a single experimental condition (i.e. removed two painted squares under the same experimental condition) he/she was asked to evaluate their grip-strength and exertion (required removal force) with the Modified Borg Scale (Appendix B). Subjects were also asked for this evaluation during the practice trials, so that they were better prepared for this portion of the experiment during data collection. The subjects'

responses were recorded along with the randomized glove order during the experimental session.

Some tool maintenance was necessary in order to ensure the tool's effectiveness was not altered during data collection trials. Since the nylon pad actually peeled the paint off the metal surface, the nylon strands needed to be clean in order to 'grip' the paint. If the same pad was used for a few consecutive removals, small pieces of paint could become stuck in-between the nylon strands, which would make the tool much less effective for paint removal. To avoid this problem, a single nylon pad was only used for a single paint removal trial (i.e. two pads were used to complete a glove condition). After data were collected, the pad was placed in a bucket of water, so that it could be cleaned and reused by the next subject. The maintenance of the plastic scraper was much simpler. After each data trial, the edge of the plastic scraper was cleaned with a paper towel and the scraper was reused.

4.5. Experimental Preparation

4.5.1. Painting Technique

In order to prepare the metal surface for painting, masking tape was used to make the four 10 cm x 10 cm squares on each of the eight working surfaces. Permanent marks were made on all eight of the working surfaces in order to ensure that the placement of the masking tape would be consistent and accurate throughout the entire experiment. The squares were than hand painted with a 2.75-inch polyfoam brush. A single 124 fl. oz. can of *Ace Royal Touch* semi-gloss latex paint was used as the coating material for the entire project.

A painting procedure was developed to make the painting process as consistent as possible. Before the masking tape was applied to the sheet metal, the surface was cleaned with a *3M* metal finishing pad and water. This combination easily removed any excess paint and/or dirt that may have been on the sheet metal. Once cleaned and dried, each square was painted with brushstrokes that were parallel to the length of the sheet metal's surface. The goal of this was to ensure that the removal process would always be parallel to the painting direction. This was done because pilot trials indicated that the tools selected for this experiment were most effective when used parallel to the painting direction rather than perpendicular to it.

After painting a single square, any excess paint was squeezed out of the polyfoam brush. Once this was done, the now 'dry' foam brush was again brought across the painted section so that the paint thickness would be even. This procedure not only made the paint thickness even, but also allowed for a consistent paint thickness to be maintained for the duration of the experiment. Additionally, the paint thickness was controlled by ensuring approximately the same amount of paint was initially on the brush prior to painting and only one painter was used. The paint was allowed to dry for approximately 24 hours in an indoor environment where the climate was controlled (~72° F and 45% humidity) 24 hours a day.

To further eliminate the possibility of minor differences in the paint application affecting the experimental results, only tools that were able to shear the paint from the metal surface were used. In other words, the tools chosen for this experiment peeled the paint off the surface. Some of the tools considered would have been much more affected by the paint thickness because they worked by disrupting

the paint through the thickness of the paint. Since much more time would have been needed to measure and finely control the paint thickness, removal tools that broke down the paint in this manner were not used. Also, since neither the cleaning process nor the coating removal task damaged (e.g. scratched, pitted, etc.) the sheet metal's surface, no changes were made in the sheet metal's surface that would cause paint to pool (i.e. inside a scratched or pitted area) in a certain areas.

Since the tools used in this experiment peeled the paint from the metal surface, the masking tape on the bottom edge (the 'starting edge') of the painted squares was always left on while the paint dried. This strip of tape was not removed from the sheet metal until just prior to data collection. This helped ensure that all of the painted sections had a consistent starting edge for the removal trials. The presence of an edge was verified with a plastic putty knife before the painted section was sprayed with water for removal. In cases where the tape did not create a well-defined edge, the plastic putty knife was used to create a starting edge.

4.5.2. Subject Electrode Placement

The flexor and extensor muscles for both the fingers and the forearm were the muscles monitored with EMG electrodes. Prior to surface electrode placement, the skin was abraded and cleaned. Sufficient electrode gel was placed on each electrode to prevent the possibility of an air gap developing during the course of data collection. The electrodes were self-adhesive, but medical tape (*3m* Nexcare® tape) was also used on every electrode to firmly secure the specific placement of the electrode to the subject's skin. Although the use of surface electrodes may not seem appropriate for the finger flexor and extensor muscles because of the many

surrounding muscles, other researchers have already established that surface electrodes will provide adequate measurements of flexor/extensor activation during hand tool use (Sudhakar 1988, Mital 1994, and Gurram 1995).

The flexor digitorum superficialis was the muscle chosen for the finger flexor EMG measurement. Electrodes were placed at the midpoint of a line running from the medial epicondyle of the humerus to the styloid process of the ulna (Gurram 1995). This was the only electrode placement used that was not the National Institute for Occupational Safety and Health (NIOSH) recommendation for electrode placement (NIOSH 1992). Although the NIOSH recommendation is appropriate for finger flexor activation, the task for this experiment also involved some wrist muscle activation. Since surface electrodes cannot distinguish signals from different muscles in close proximity, the location used by Gurram *et al.* was used. The Gurram study showed that EMG measurements of the finger flexors were correlated with changes in grip force with this electrode placement during hand tool use. Pilot studies also confirmed that the Gurram placement seemed to be less influenced by wrist muscle activation for this study.

The extensor digitorum communis was the muscle monitored for finger extensor EMG measurements. Electrodes were placed along a line starting at the lateral epicondyle of the humerus and ending at the midpoint of the styloid processes of the radius and the ulna. The exact placement of the electrodes depended on the distance between those two points and was 1/4 of the total line length when starting from the epicondyle (NIOSH 1992).

The biceps brachii was the muscle monitored for forearm flexor measurements. Electrodes were placed along a line staring from the base of the biceps tendon and ending at the acromion. Electrode placement was 1/3 the distance of the line segment away from the base of the biceps tendon. The triceps brachii was the muscle monitored for forearm extensor measurements. Electrodes were placed along a line starting from the olecranon and ending at the acromion. Placement was 1/3 of the segment distance away from the olecranon (NIOSH 1992).

The *Biopac* surface electrode system is a bipolar electrode system where each set of electrodes requires a separate ground. Since four muscles were being monitored, four ground locations were needed. The lateral epicondyle of the humerus was used for the biceps and the medial epicondyle was used for the triceps. The other two grounds were placed next to each other on the subject's iliac crest.

4.6. Data Analysis

4.6.1. Force Data

As mentioned above, force data were collected from each trial. The experimental procedures and working surfaces were designed so that a force reaction plate could be used to measure the removal exertion forces that were used while performing the coating removal task. The force plate was calibrated prior to data collection and the calibration was re-verified after data collection was complete. Coating removal force data were collected at 200 Hz for the entire duration of the removal task.

To analyze the force data, average 'removal impulses' (the periods of active removal exertions) were determined for each experimental condition by calculating the vector sum (Equation 1) of the applied forces (Figure 7b).

Vector Sum = (X^2+Y^2+Z^2)^0.5 (Equation 1)
where X = fore-aft forces, Y = lateral forces, and Z = Normal forces

The removal impulse was defined from when the subject first started applying a removal force to the surface until when the subject completed a given exertion on the time scale. To ensure only the active removal impulse was examined, shear force rather than normal force was used to define the starting and ending points of the impulses. This was done incase a subject rested the tool on the surface prior to or after completing a removal impulse; however, this was not typically a problem during the removal trials. The average removal impulses were then used to determine two of the dependent force variables: average removal force (the average value for the vector-summation (Eq. 1) of the active removal exertion period) and peak removal force (maximum value for the active removal exertion period). The other force variables were determined in the same manner and they were average normal (Z forces only) force, peak normal force, average shear (vector sum of X and Y forces) force, and peak shear force.

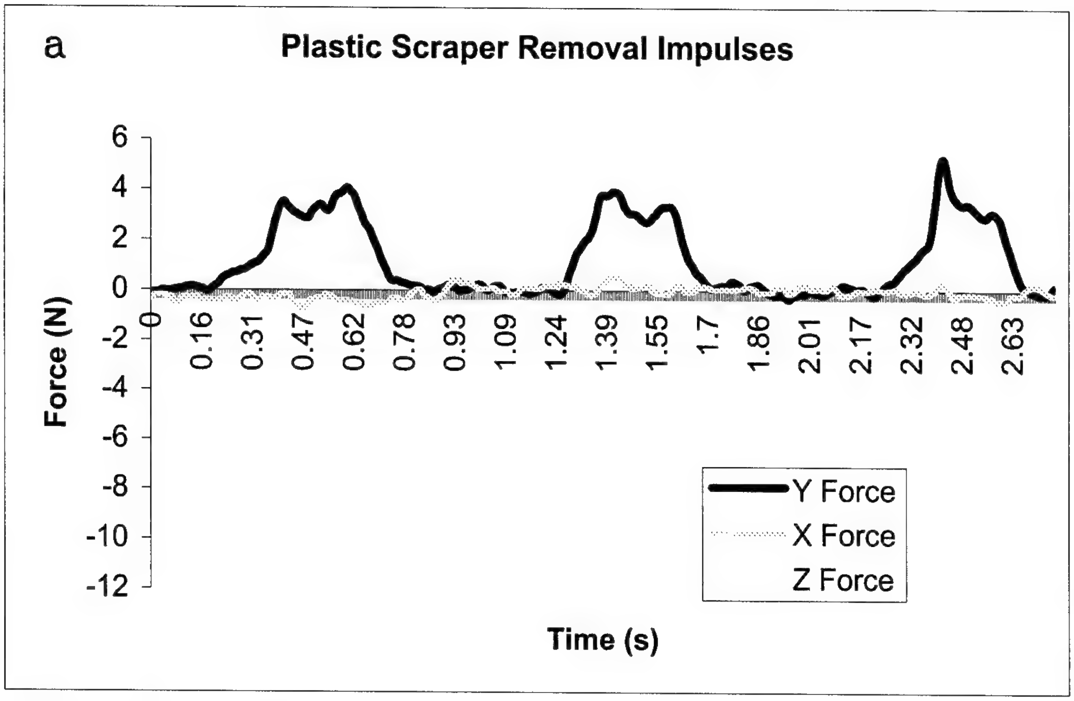

Figure 7a. An example of force data collected during a coating removal trial with the plastic scraper.

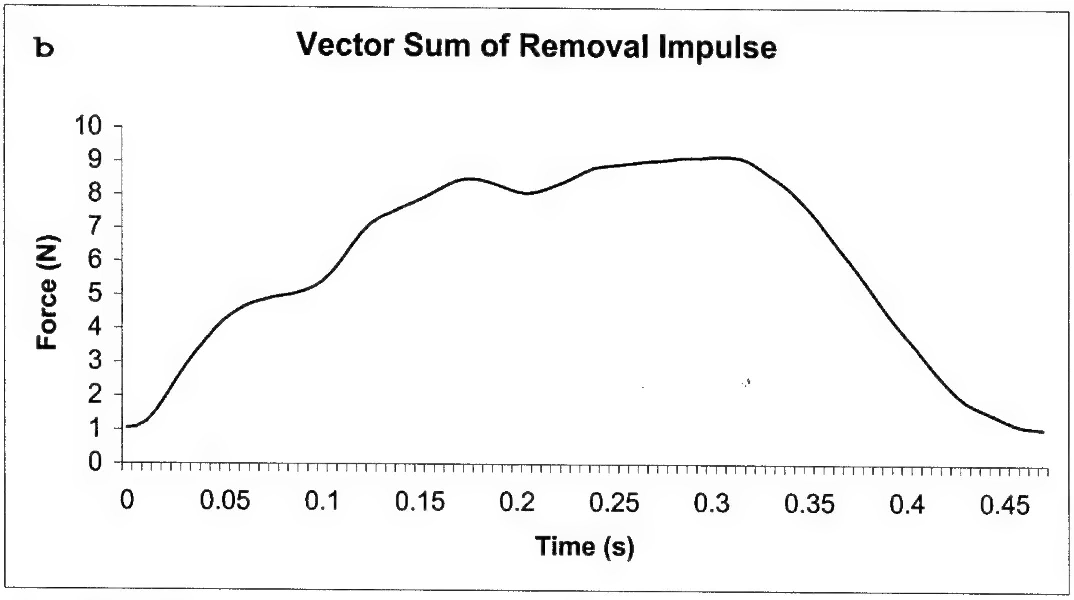

Figure 7b. The vector-summation (Equation 1) of the second removal impulse from the data presented in part (a), which was used for determining average removal force and peak removal force.

The removal impulse used to determine the average and peak removal forces was dependent on the tool that was being analyzed. When subjects used the plastic scraper, the removal method (the number of exertions used and the distance covered during each exertion) was very similar for all of the subjects. Each removal exertion started at the bottom edge of the painted section and continued until the subject had scraped across the entire 10 cm length of the painted section. In almost all cases, the second removal impulse was used for data analysis of a particular trial. In the very few cases where the second removal impulse was not used, it was because a removal error (e.g. the tool slipped in the subject's hand) occurred. Appendix C provides a complete listing of which impulses were used for data analyses. The force data points (average removal force, peak removal force, average normal force, peak normal force, average shear force, and peak shear force) were determined for each of the two coating removal trials and were then averaged.

A different averaging technique was used to determine the average impulse for the nylon pad trials. This was done because most of the subjects used at least twice as many removal impulses to complete a trial with this tool. To determine an average impulse for a single trial, typically two to three representative (visual average) removal impulses from that trial were averaged together. Representative removal impulses were selected from a trial by grouping three or four (depending on the amount of impulses used to complete the removal) consecutive removal impulses together. Once grouped, a representative impulse from each group was selected (see note on figure 8b). The first and last removal impulses were not usually included in the groupings and they were never selected as a representative impulse. The

representative impulses were then averaged together and all of the dependent force variables for the single trial were determined from this average impulse. After data points were determined from each trial, the data analysis was the same as it was for the plastic scraper impulses. A table of the removal impulses selected for the nylon pad removal trials is included in Appendix D.

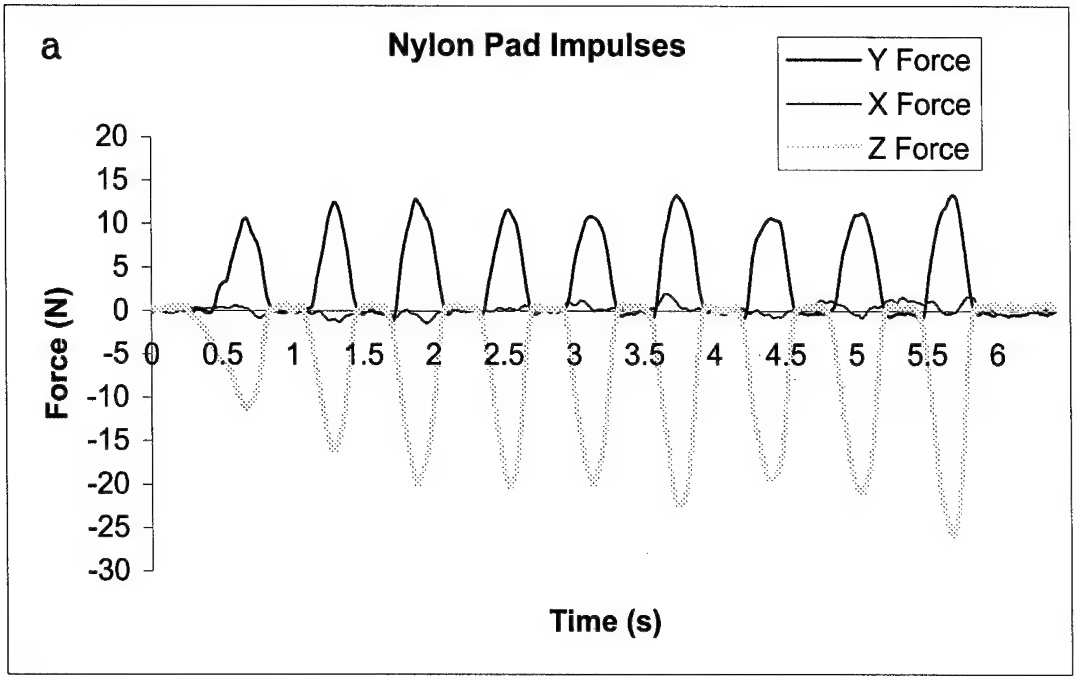

Figure 8a. An example of force data collected from a single removal trial with the nylon pad.

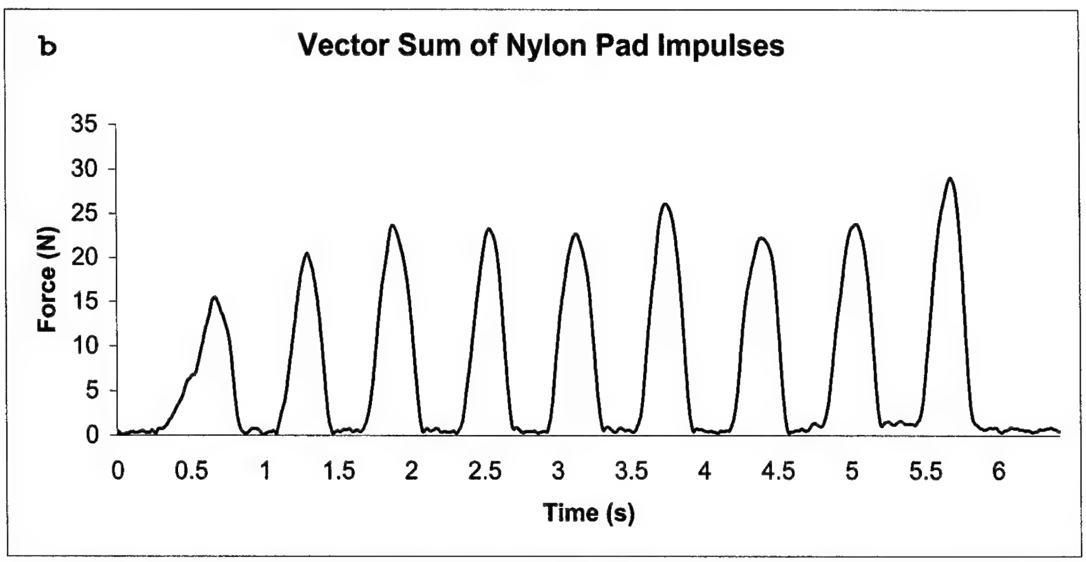

Figure 8b. A graph of the vector-summed impulses presented in figure 8a.
Note for Fig. 8b: This trial was divided into two groups of consecutive impulses. The first group would be the second impulse to the fifth impulse and the second group would be the sixth impulse to the eighth impulse. Out of those groups, the fourth impulse would be selected as the 'representative' impulse from the first group and the eighth impulse would be selected as the representative impulse from the second group.

4.6.2. EMG Data

To evaluate muscle activation level, EMG data were collected at 1000 Hz while the subjects performed maximal muscle exertions. To minimize the effect of muscle movement, the maximal exertions were taken while the subject's arm was in approximately the same position as it were for the experimental trials. To quantify a maximal flexor exertion, the subject placed the tips of his/her fingers on the edge of the working surface and maximally flexed their fingers. For finger extension, the subject placed the tips of their fingers under the edge of the working surface/force plate combination and performed a maximal finger extension. The maximal triceps activation level was determined by the subject placing their palm on the working surface and maximally extending their forearm. Finally, the maximal biceps activation level was determined by performing a maximal forearm flexion while maintaining a 90-degree angle at the elbow.

In addition to the basic maximal exertions, data were also collected while the subjects performed a maximal grip while holding each tool. Maximal grip exertions were performed after the subject completed his or her practice trials with that tool. Subjects were asked to hold each tool with the grip they had learned from the practice trials and then perform a maximal voluntary grip for approximately four seconds.

Similar to the maximal trials, experimental EMG data were collected at 1000 Hz for the entire duration of the removal trials. To analyze the EMG data (both the trial data and the maximal exertions), a 5-point root mean square (RMS) averaged signal was calculated from the filtered (30 - 500 Hz band-pass filter) raw EMG signal (Figure 9a). The RMS signals were then smoothed with a 5 Hz low pass filter (Figure

9b) (NIOSH 92). Once the signals were processed with this technique, the static grip time periods (the time between active removal exertions) and the active removal time periods were identified by looking at the activation patterns of the four muscles being monitored.

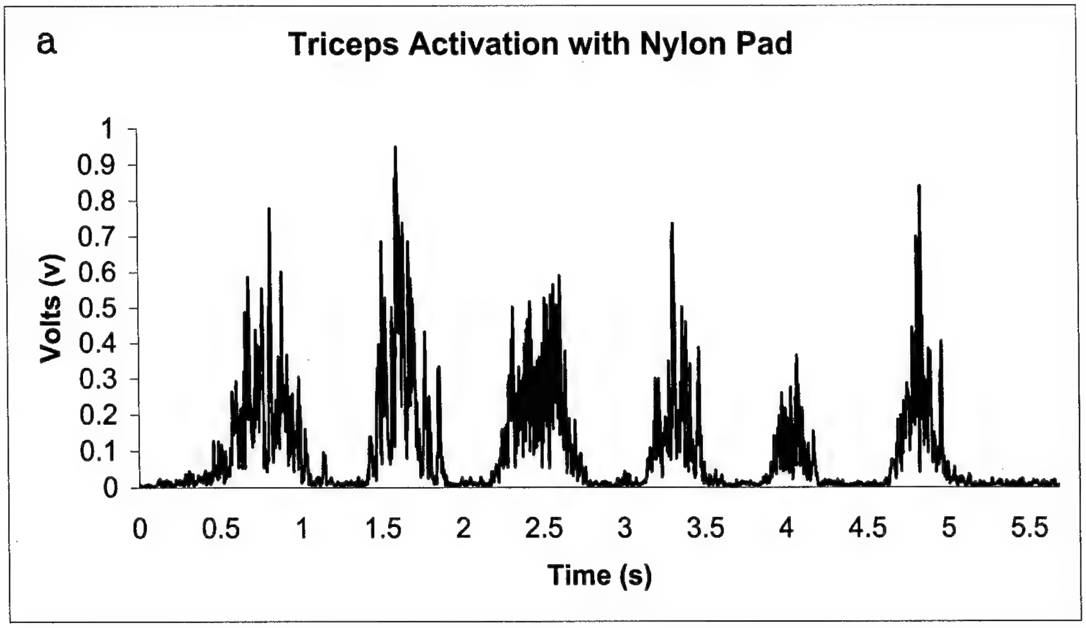

Figure 9a. EMG data from a subject's triceps during a nylon pad removal trial after it was band filtered (30-500 Hz) and averaged with a 5 pt RMS algorithm.

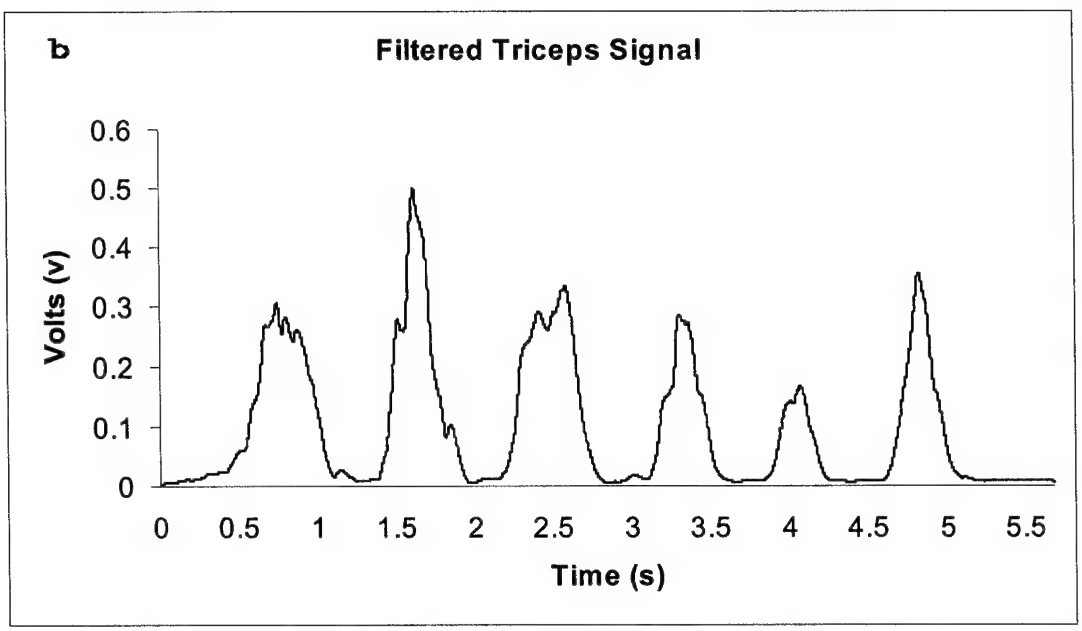

Figure 9b. The data presented in 9a after it had been filtered with a 5 Hz low pass filter.

Once the temporal information was determined for each trial, the average (A) EMG values for the each muscle during the active time periods (A-flexors, A-extensors, A-triceps, and A-biceps) were found. To evaluate these average values, they were normalized with the subject's average maximum EMG values (Sudhakar 1988). A one to two second time period from the processed EMG data for the maximum contractions was used to determine the average maximum (M) EMG values (M-flexors, M-extensors, M-triceps, and M-biceps) for each muscle. For example, to determine the normalized value for the flexors during the active removal period, the following equation (Equation 2) was used:

$$\frac{\text{A-Flexors}}{\text{M-Flexors}} * 100 \quad \text{(Equation 2)}$$

The result of this equation was the percentage of the maximum voluntary EMG (%MVC) for the flexors. New maximum EMG values were needed for each day of experimental testing. This could not be avoided because the electrodes were re-applied on each day of testing and the maximum values for that day's specific electrode placement were needed. The %MVC for each muscle during the active removal periods were found for all trials and these were the values used for the statistical analyses.

A very similar approach was used to analyze the static grip time periods, but there were two main differences. The first difference for the analyses during these time periods was only the EMG data for the extensors and the flexors were analyzed. The second difference for these time periods was a different maximum value was used to determine the %MVC for the flexors. The new maximum flexor value (M-

flexors-static) was determined from the data collected when the subjects performed maximal grips with each tool. The M-flexors-static value was found by calculating the average value for a one to two second window of the processed maximal grip data. The extensor %MVC during these time periods was again determined by using each subject's M-extensors values.

When analyzing the active EMG time periods not all of the data were used. The active EMG time periods that were selected were chosen because they corresponded with the same impulses that were used for the force analyses (appendices C and D). The static grip time periods used for analysis depended on the tool being analyzed. Since the overwhelming majority of removal trials with the plastic scraper used just three removal impulses, the static grip periods in-between the first and second and the second and third removal impulses were used. Since the nylon pad removal trials tended to use more removal impulses, more static grip time periods were also present. Therefore, all of the static time periods after the static period in-between the first and second impulse until the second to last static time period were used.

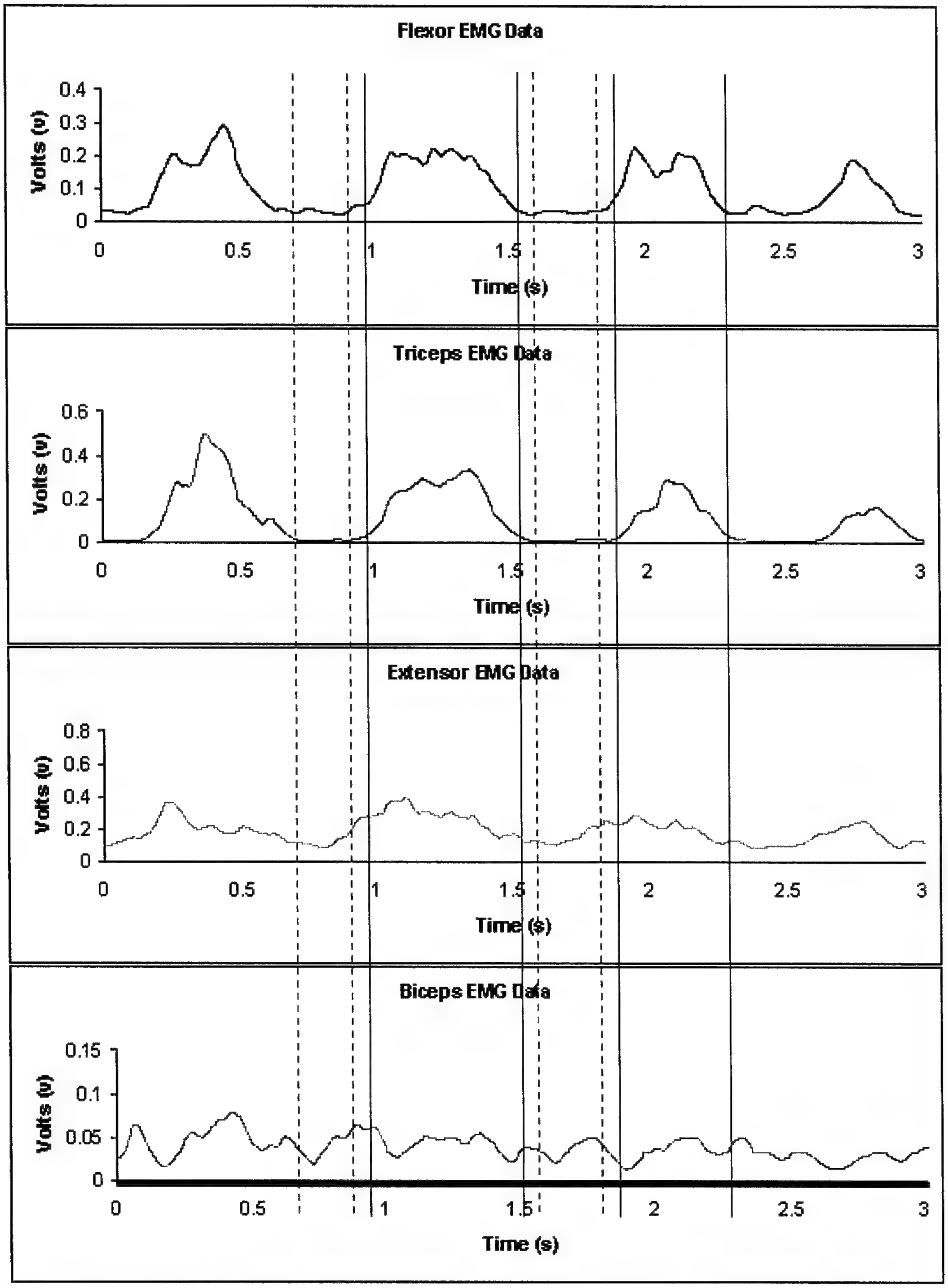

Figure 10. EMG data (after processing) collected from four muscles during a removal trial with the nylon pad.

Note: The time periods of dynamic removal (data in-between solid lines) were separated from the periods of static grip force (data in-between dashed lines) by concentrating on the timing information present in the data from the flexors and the triceps. The data points in-between the dashed and solid lines were considered a transitional period and was not included in either of the other time periods.

4.6.3. Statistical Analysis

To test for statistical differences for each dependent variable, analysis of variance (ANOVA) was performed. *Post hoc* analyses (Least Squares Difference, LSD) were also performed to compare the gloved conditions to the barehanded condition. Other research efforts have shown that using these statistical methods on data gathered from human subjects is appropriate for drawing data-supported conclusions (Keppel 1991).

V. Results

5.1. Force Analysis

5.1.1. Average Removal Impulses Across Both Tools

The results of the MANOVA analyses (Table 3) on the average removal force (the vector-summation of the forces) revealed that there were significant differences based on the tool ($p<0.01$, Figure 11) and the glove ($p<0.01$, Figure 12) used, as well as a toolxglove interaction effect ($p<0.05$, Figure 13). Force removal data for one subject were not included because the videotape of his removal trials showed that he used an inconsistent removal method during the plastic scraper removal trials ($n = 8$).

Table 3. MANOVA results for the average removal force data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	12940.04	7	239.47	54.03	**0.00016**
Glove	12	23.28	84	8.80	2.64	**0.0047**
GloveXTool	12	18.57	84	8.69	2.14	**0.023**

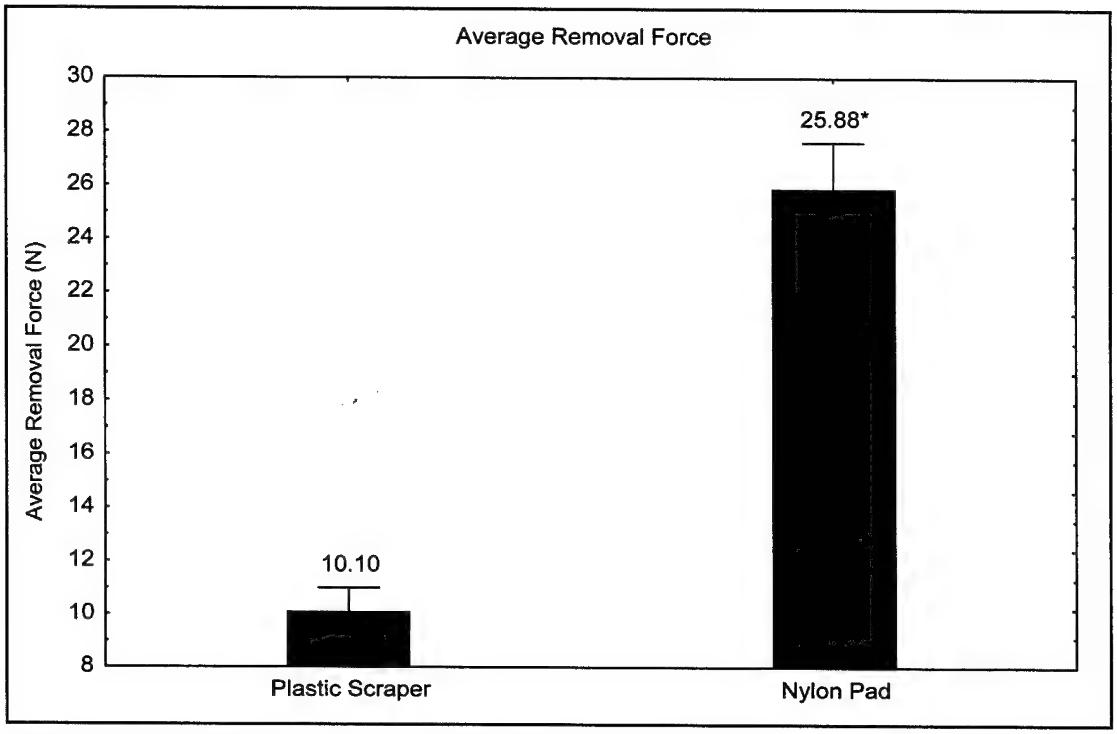

Figure 11. Average removal force per removal tool
Note: * indicates significantly different (p<0.01) from plastic scraper.

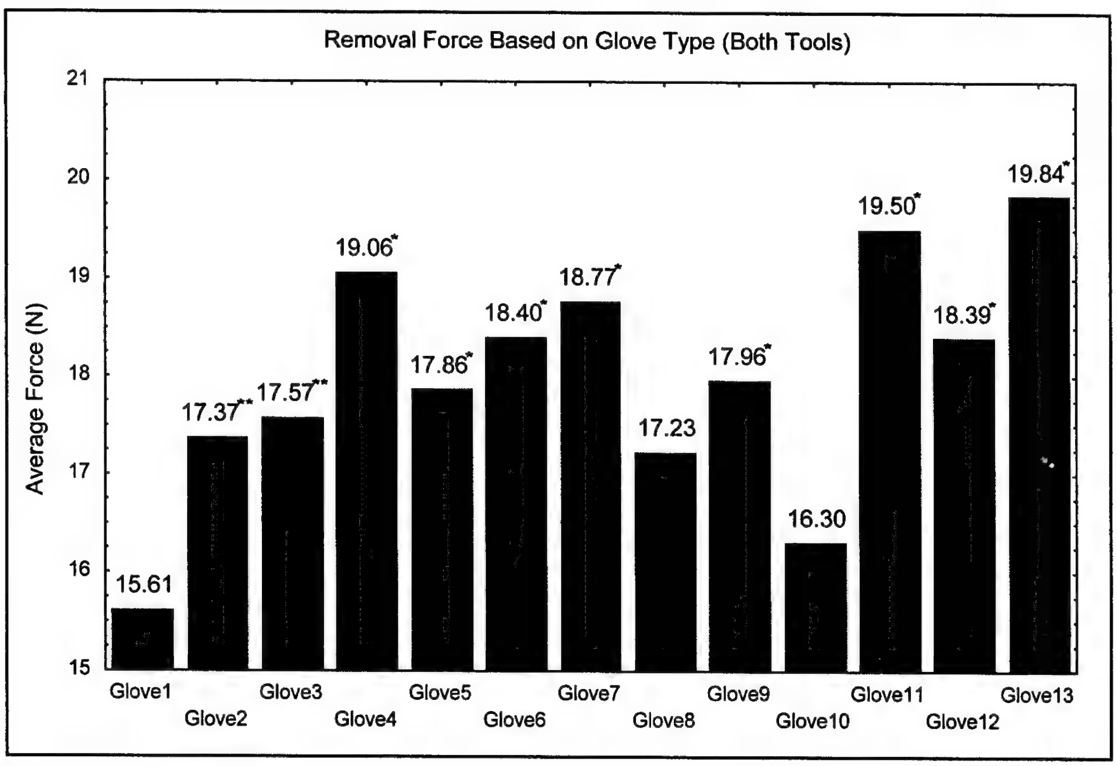

Figure 12. Average removal forces per glove condition
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

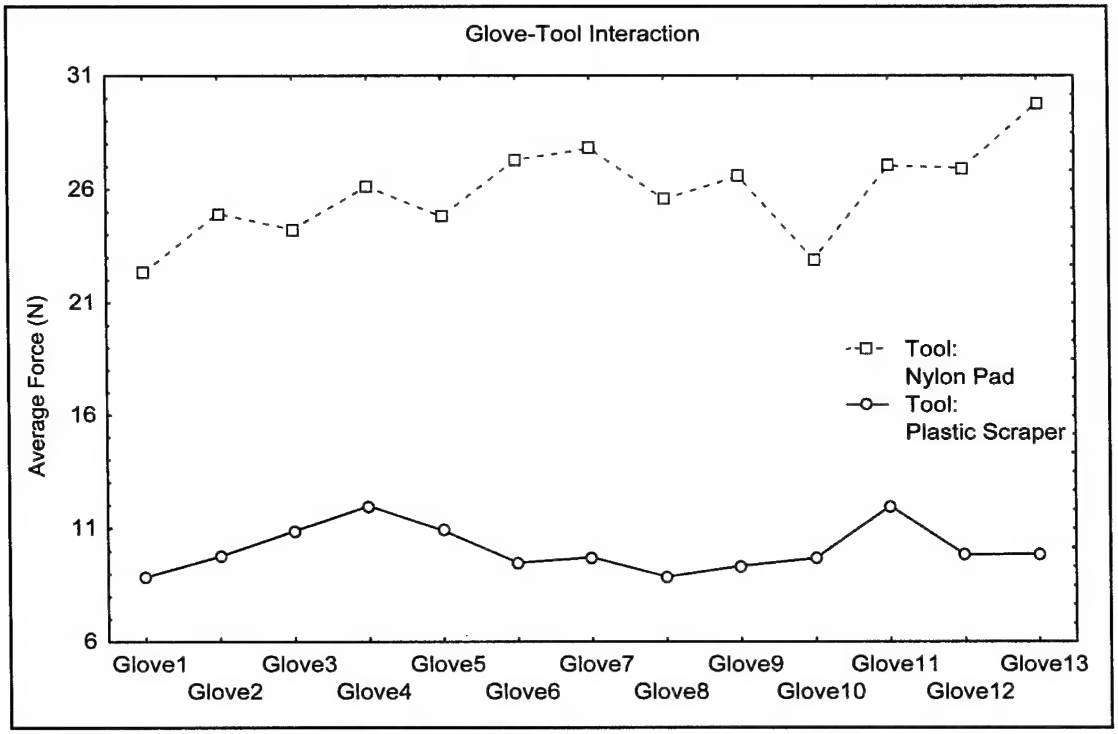

Figure 13. Glove-Tool interaction for average removal forces.

5.1.2. Removal Force for Each Tool

Since there was a significant interaction effect, the effect that the gloved conditions had on each tool was further examined. ANOVA analyses were conducted on each tool (plastic scraper: $n = 8$; nylon pad: $n = 9$) to determine how the glove conditions affected the average force and peak force. For the plastic scraper, the glove condition was a significant main effect ($p<0.1$, Figure 14) on the average force, but there was not a significant main effect ($p=0.16$, Figure 14) when the peak force was examined. For the nylon pad, the glove condition did have a significant main effect ($p<0.01$, Figure 15) on the average force and the peak force.

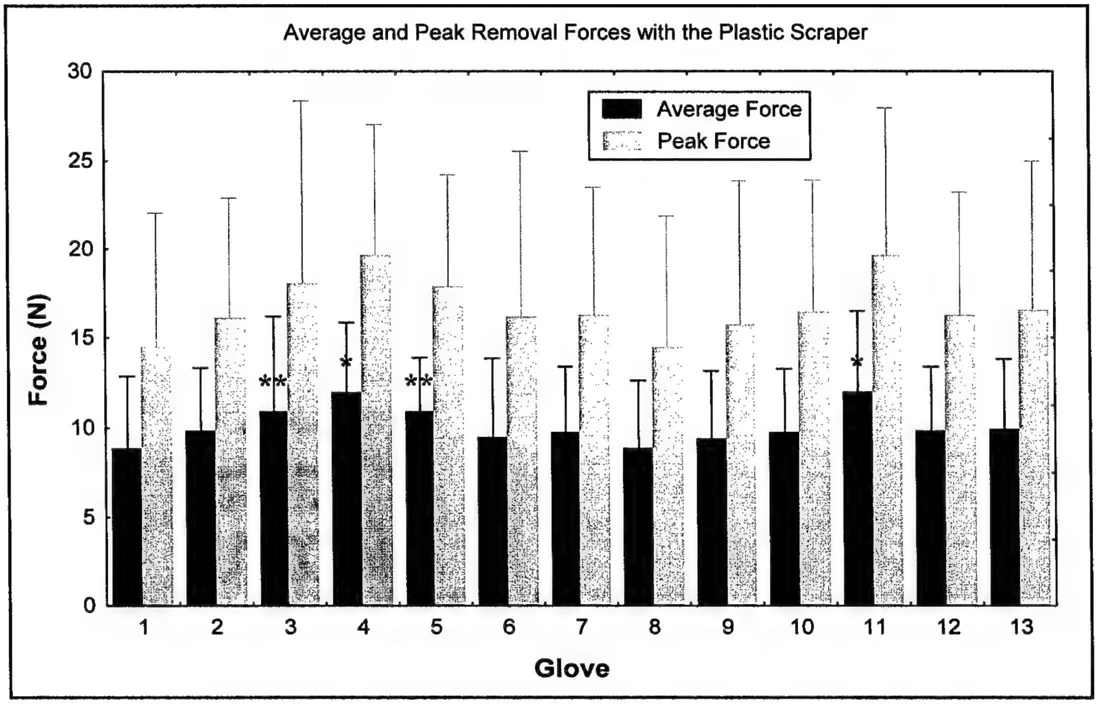

Figure 14. A comparison of the average and peak forces for removal trials with the plastic scraper.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

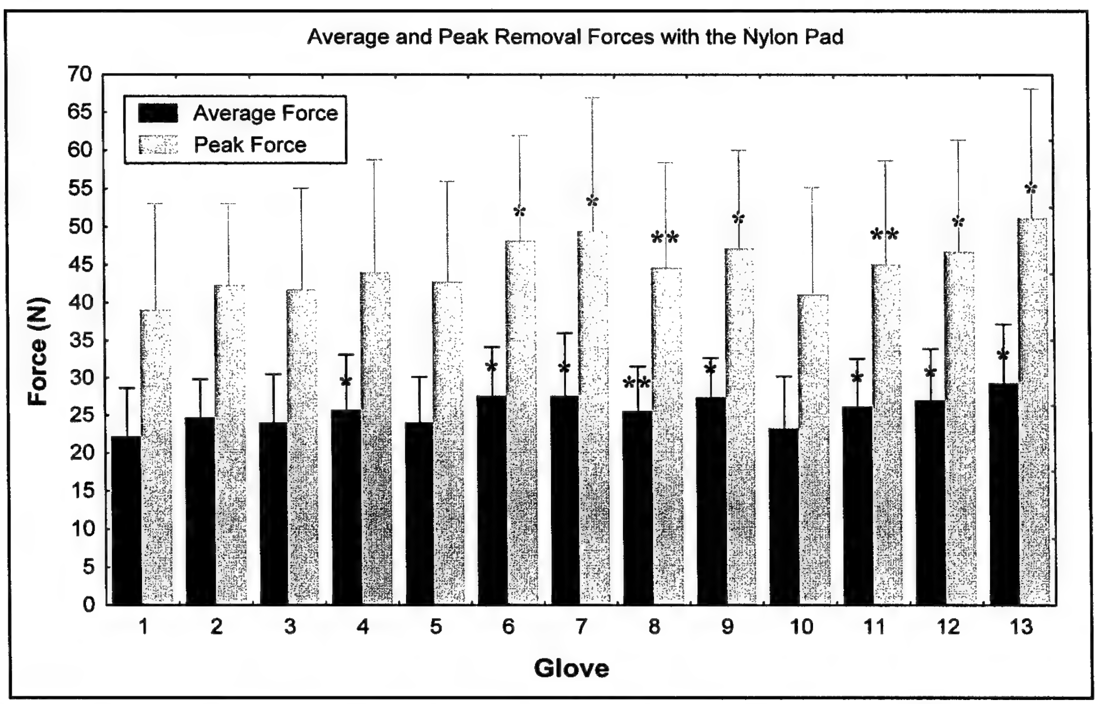

Figure 15. A comparison of the average and peak forces for removal trials with the nylon pad.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

5.1.3. Shear Forces for Each Tool

ANOVA analyses were also performed on the shear removal forces. For the plastic scraper, the glove condition was a significant (p<0.1, Figure 16) main effect on average shear force, but it was not significant (p=0.11, Figure 16) for peak shear force. For the nylon pad, glove condition was a significant (p<0.05, Figure 17) for both the average shear force and the peak shear force.

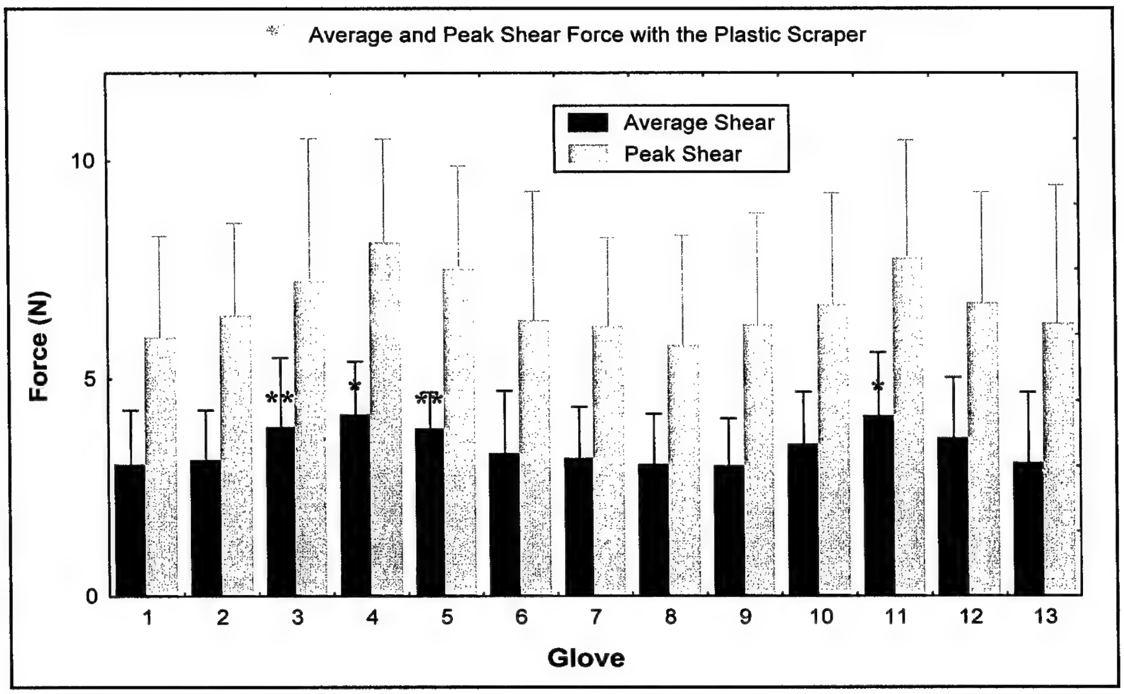

Figure 16. A comparison of the average and peak shear forces for removal trials with the plastic scraper.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

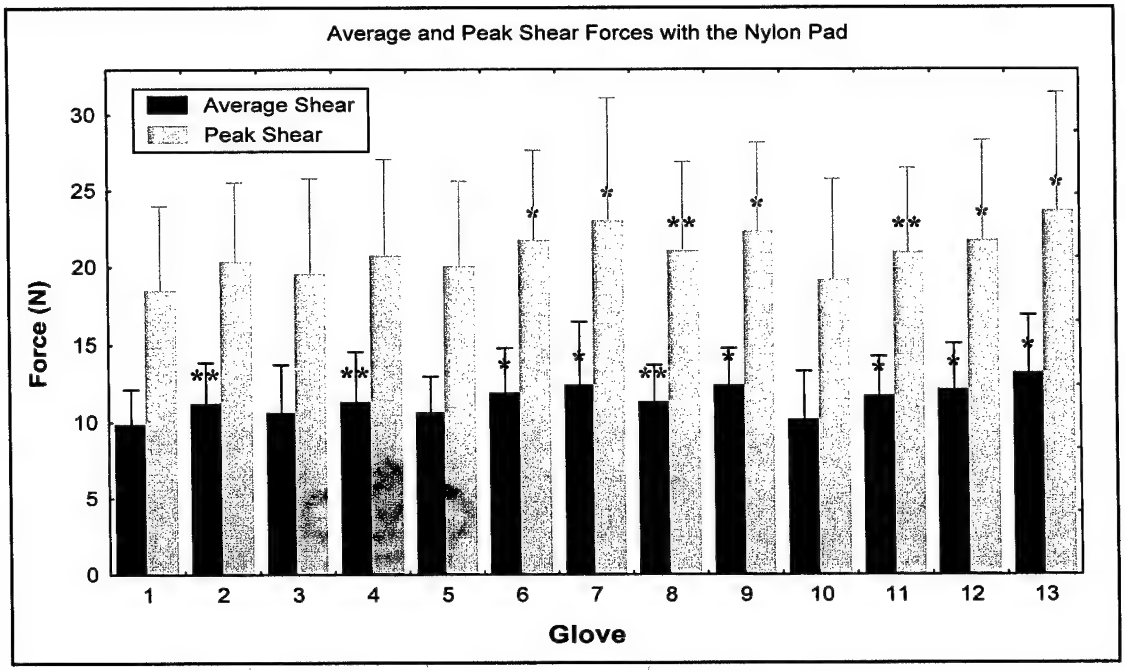

Figure 17. A comparison of the average and peak shear forces for removal trials with the nylon pad.

Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

5.1.4. Normal Force for Each Tool

The next force analyses performed were ANOVA analyses of the normal forces. The glove condition was a significant ($p<0.1$, Figure 18) main effect for the average normal force when the plastic scraper was used; however, the glove condition was not a significant ($p=0.21$, Figure 18) main effect for peak normal force when the plastic scraper was used. For the removal trials with the nylon pad, the glove condition was a significant ($p<0.01$, Figure 19) main effect for both the average and the peak normal force.

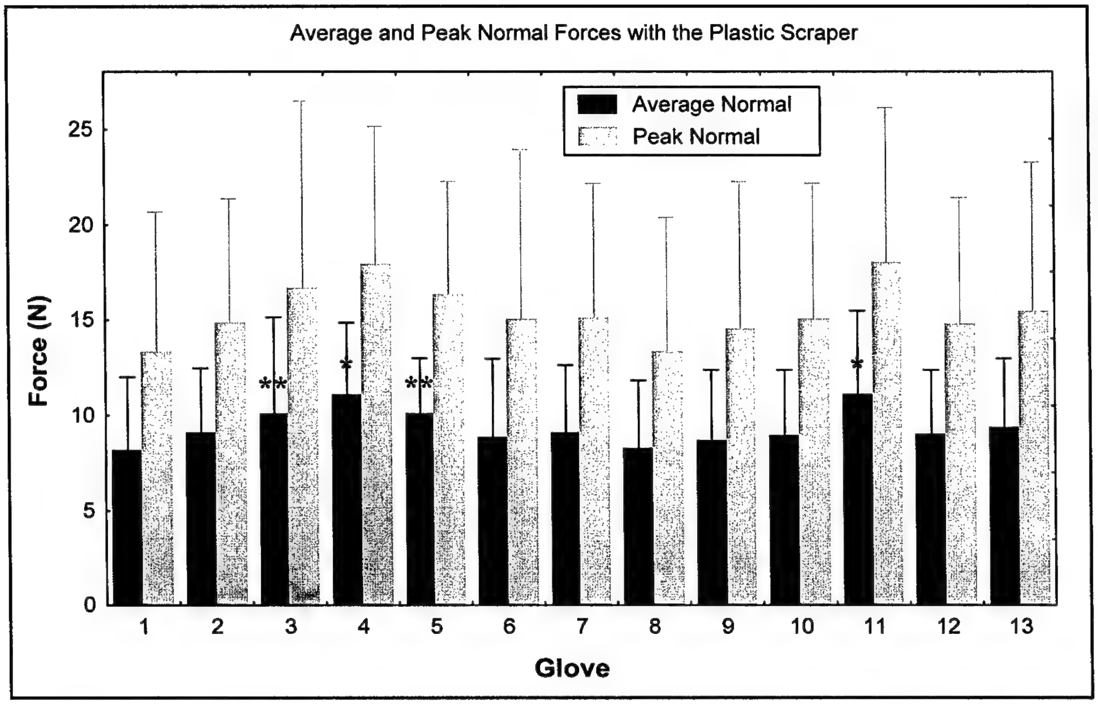

Figure 18. A comparison of the average and peak normal forces for removal trials with the plastic scraper.

Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

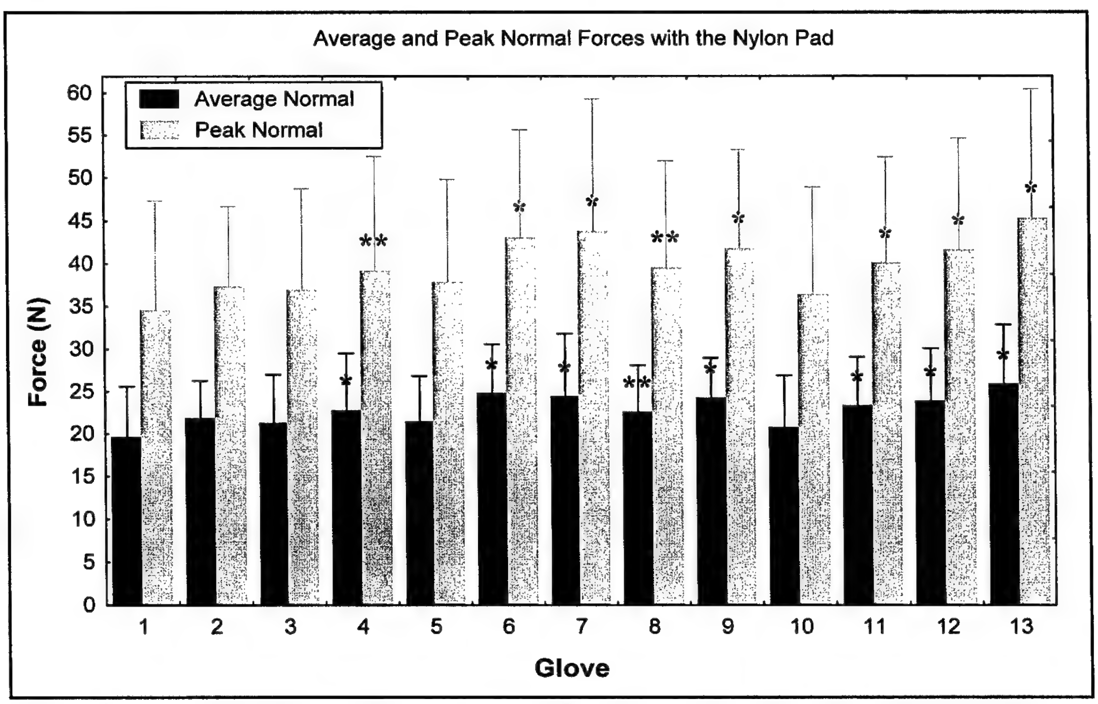

Figure 19. A comparison of the average and peak normal forces for removal trials with the nylon pad.

Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

5.1.5. Percent Shear and Normal Forces for Each Tool

The final analyses conducted involving the force data were comparisons of the shear and normal forces to the vector-summation of the removal forces. To make this comparison, the average shear and normal forces were converted into a percentage of the average vector-summation of the removal forces. ANOVA analyses determined that glove type was not a significant main effect for both the shear and the normal forces for each tool. The p-values for the plastic scraper were 0.76 for the average normal force and 0.15 for the average shear force (Figure 20). The p-values for the nylon pad were 0.54 for the average normal force and were 0.67 for the average shear force (Figure 21).

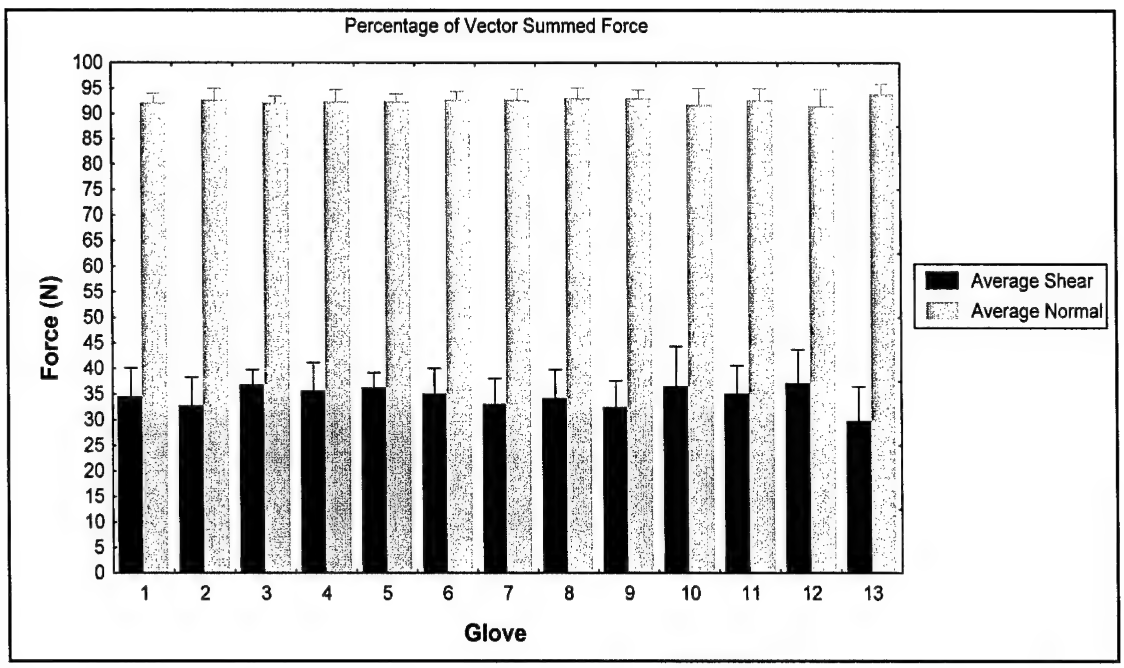

Figure 20. Average shear and normal force as a percentage of the vector-summed removal forces for the plastic scraper.

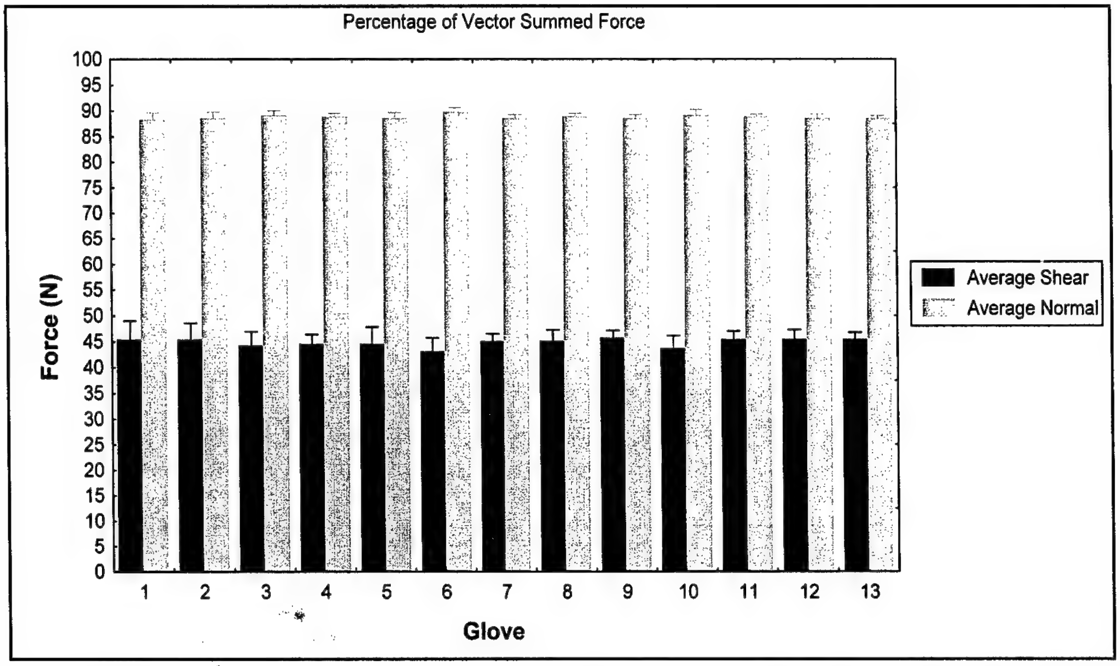

Figure 21. Average shear and normal force as a percentage of the vector-summed removal forces for the nylon pad.

5.2. EMG Analysis

5.2.1. Static EMG Analysis

Again, the periods of static grip occurred after the first removal exertion, but only during the time periods when the subjects were definitely not in contact with the working surface (Figure 10). During these time periods, only EMG data for the finger flexors and extensors were examined as percentages of their maximums. MANOVA analyses (Table 4) were first conducted on the finger flexor data with both tool and glove as the main effects. For these analyses, only six subjects had a complete set of EMG data for both tools (n = 6). The results of these analyses revealed that tool type was not a significant main effect (p=0.35) and there was no interaction between the two effects (p=0.33); however, glove type was a significant (p<0.01, Figure 22) main effect.

Table 4. MANOVA results for static flexors EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	279.96	5	259.56	1.08	0.35
Glove	12	27.87	60	11.17	2.50	**0.010**
GloveXTool	12	13.60	60	11.68	1.17	0.33

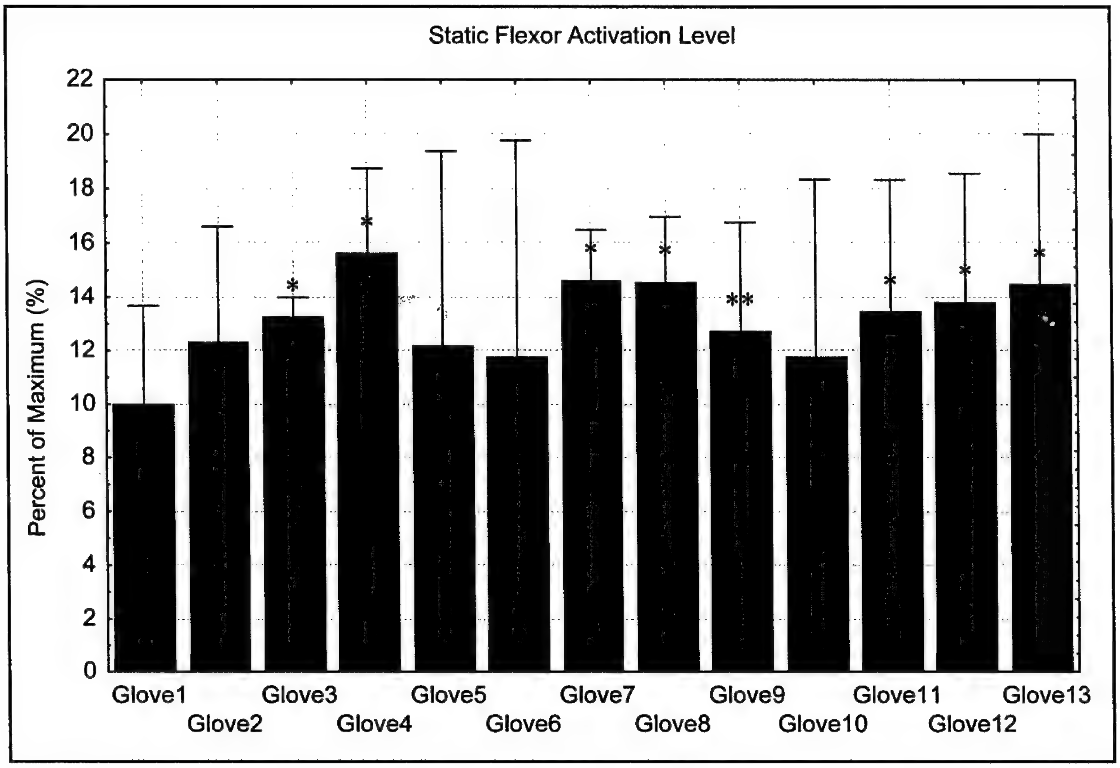

Figure 22. Flexor activation levels as a percent of maximum during the static grip periods.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

MANOVA analyses (Table 5) were conducted on the finger extensors data from the static time periods in a similar manner. For this analysis, seven of the subjects had a complete set of data for the finger extensors ($n = 7$). The results of this analysis revealed that tool type ($p<0.05$, Figure 23) was a significant main effect, but glove condition was not. The interaction between the two main effects was not significant. The average flexor activation level (across all glove conditions) for the

plastic scraper was 13.21% and the average activation level for the nylon pad was 17.03%.

Table 5. MANOVA results for static extensor EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	663.29	6	84.57	7.84	**0.03**
Glove	12	11.01	72	7.71	1.42	0.17
GloveXTool	12	7.00	72	5.67	1.23	0.28

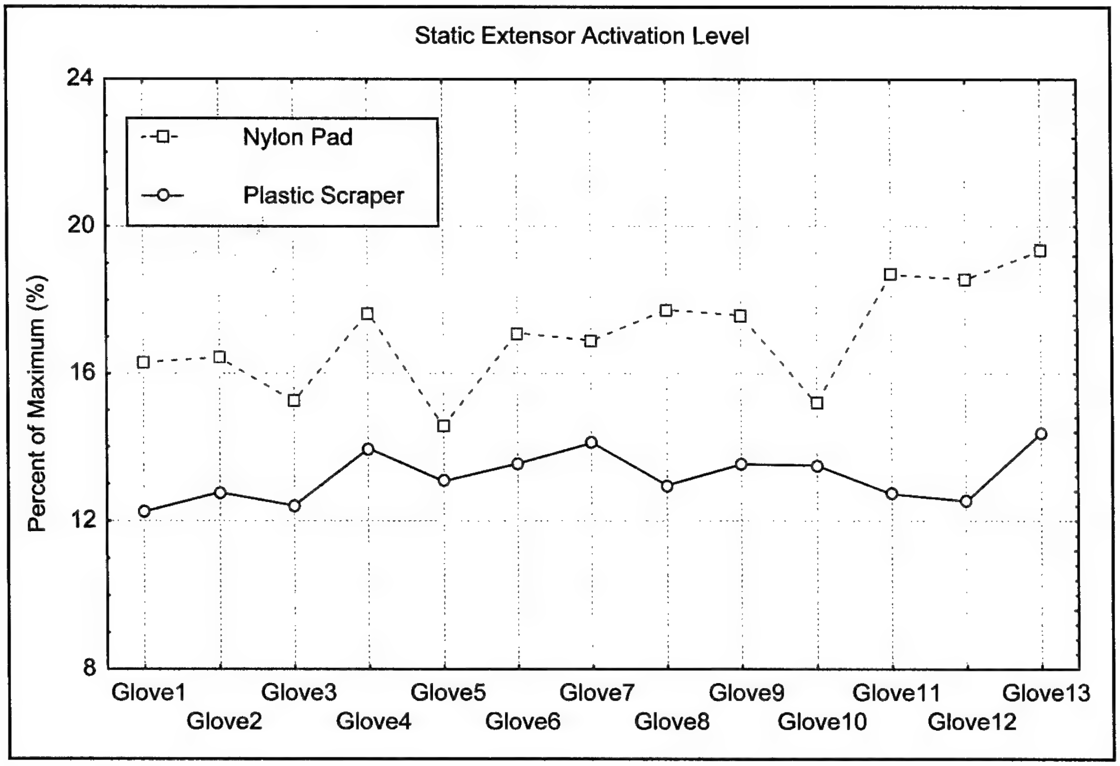

Figure 23. Extensor activation levels as a percent of maximum during the static grip periods.

5.2.2. Dynamic EMG Analysis

The second group of EMG time periods analyzed were the active removal time periods (Figure 10). EMG data for the flexors, extensors, biceps, and triceps muscles were analyzed as a percentage of their maximums during these time periods.

MANOVA analyses were conducted with both the tool and glove condition as the main effects. Tables 6-9 summarize the results of the MANOVA analyses.

Table 6. MANOVA results for dynamic flexors EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	899.15	5	447.04	2.01	0.22
Glove	12	33.9	60	16.22	2.09	**0.03**
GloveXTool	12	25.67	60	19.67	1.31	0.24

Table 7. MANOVA results for dynamic extensor EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	0.27	6	203.14	0.0013	0.97
Glove	12	13.58	72	11.03	1.23	0.28
GloveXTool	12	13.89	72	14.04	0.99	0.47

Table 8. MANOVA results for dynamic biceps EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	37.84	6	50.51	0.75	0.42
Glove	12	0.59	72	0.98	0.61	0.83
GloveXTool	12	1.13	72	0.97	1.17	0.32

Table 9. MANOVA results for dynamic triceps EMG data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	4672.89	6	373.16	12.52	**0.012**
Glove	12	19.97	72	6.54	3.05	**0.0016**
GloveXTool	12	7.94	72	6.72	1.18	0.31

The MANOVA analyses revealed that there were only three significant main effects: glove for the dynamic flexors (Figure 24), tool for the dynamic triceps (Figure 25), and glove for the dynamic triceps (Figure 25).

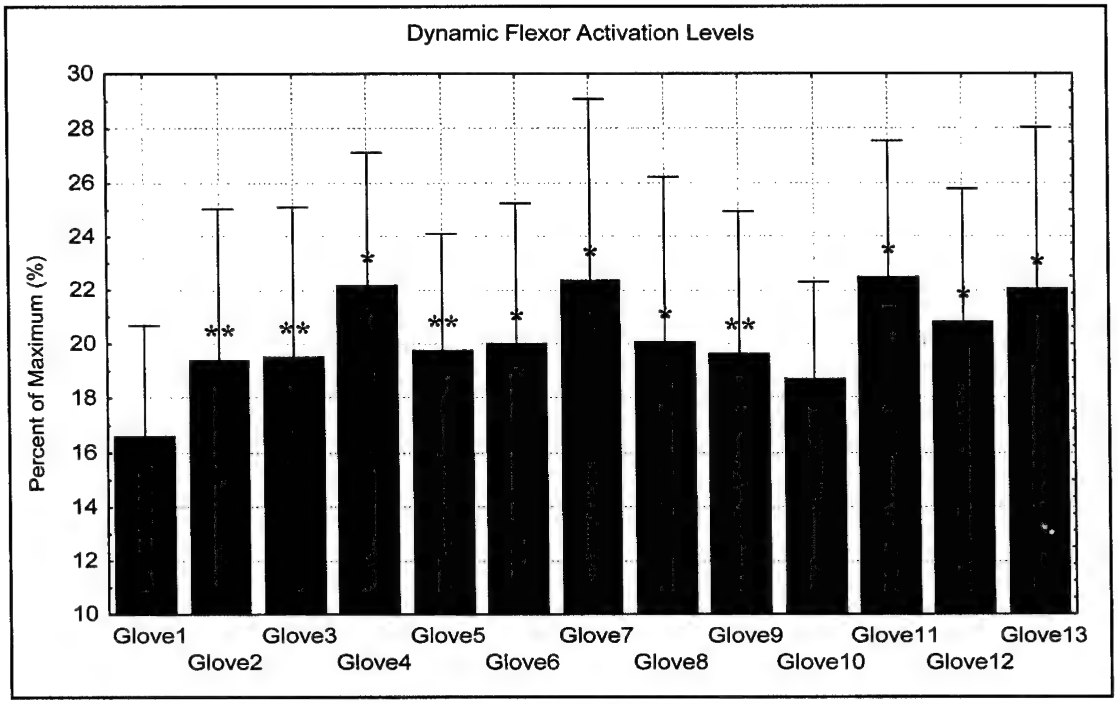

Figure 24. Flexor activation levels as a percent of maximum during active removal time periods.

Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

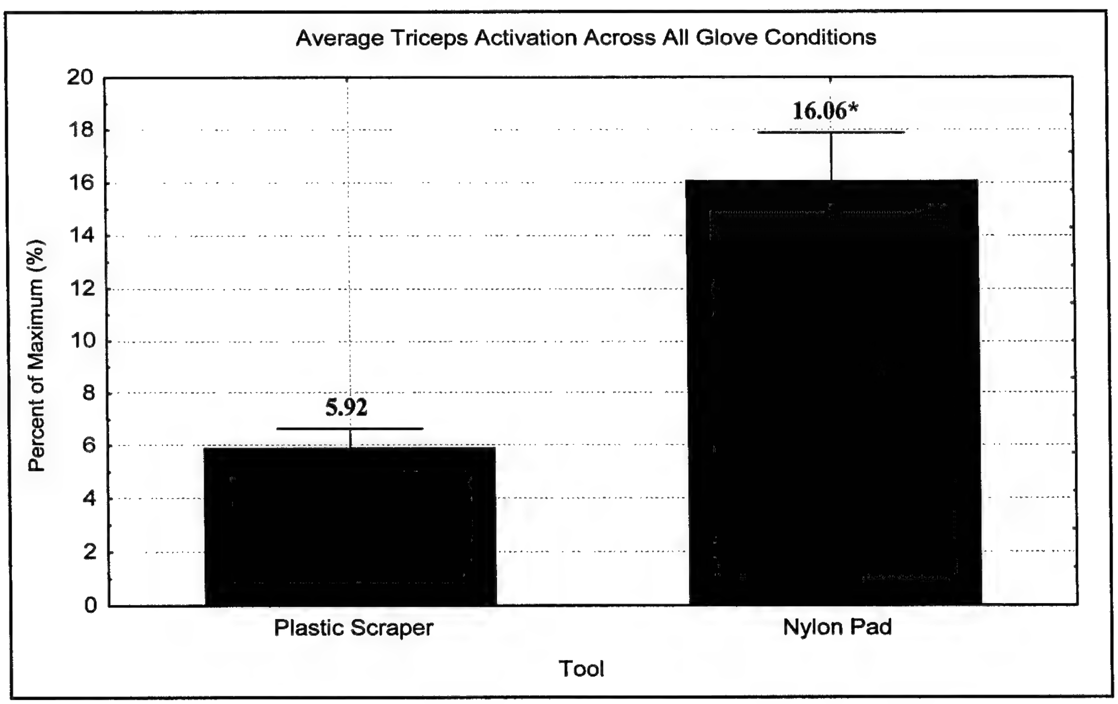

Figure 25. Average triceps activation level during the active removal time periods across all glove conditions.

Note: * indicates significantly different (p<0.05) from plastic scraper.

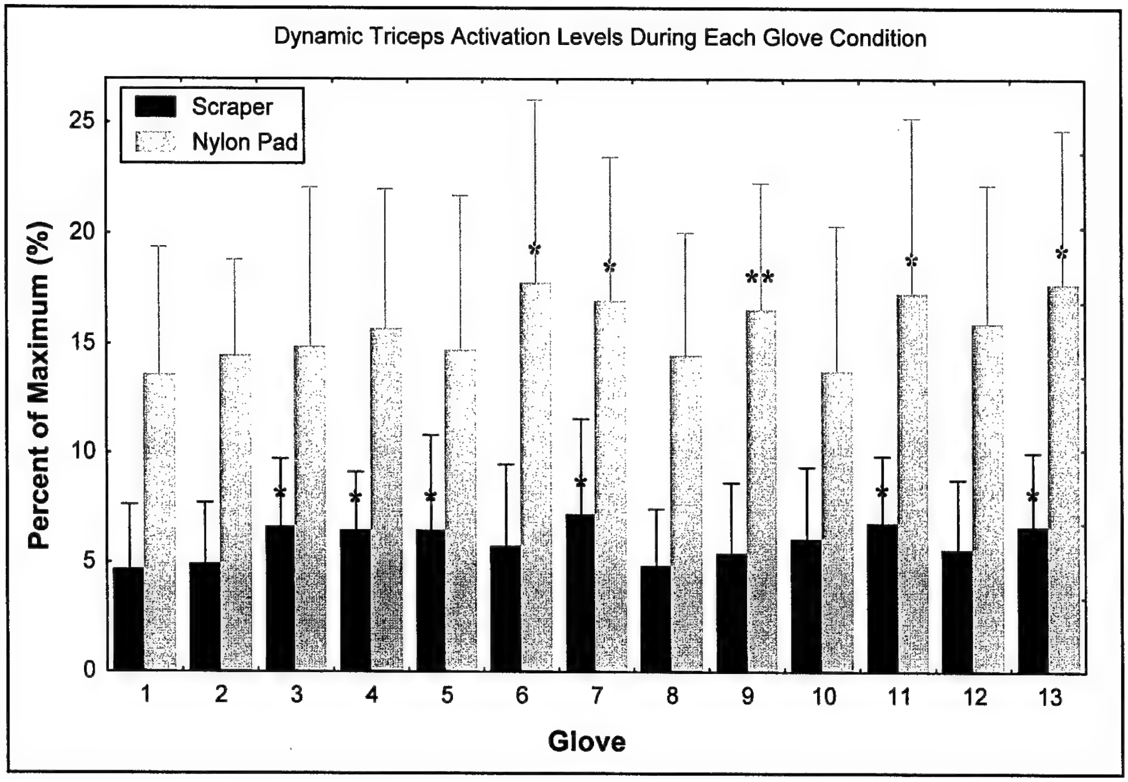

Figure 26. Triceps activation levels during the active removal time periods for each glove condition.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.1) form Glove 1.

5.3. Subjective Force Assessments

MANOVA analyses were conducted on the subjects' assessments of their grip strength (grip force required to hold on to the tool) and the removal exertion (level of force required to remove the paint) requirements. The results from these analyses revealed that there were significant differences based on the tool ($p<0.05$, Figure 27) and the glove ($p<0.01$, Figure 29) main effects for grip strength requirements, but only the tool ($p<0.01$, Figure 27) main effect was significant for the removal exertion requirement. Since the tool was a main effect, the subjective scores were re-examined for each tool separately. The results of this analysis revealed that the glove

condition was not a main effect for the plastic scraper, but it was a main effect for the nylon pad (p<0.05, Figure 28).

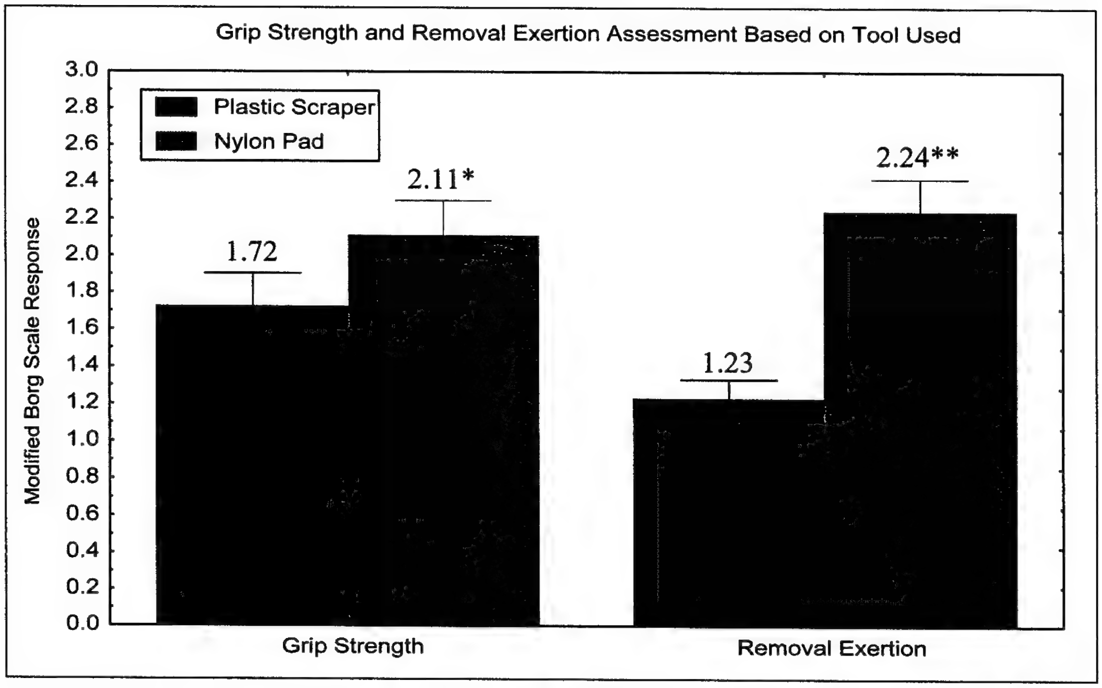

Figure 27. Average response using the modified Borg scale for grip strength and exertion requirements for each tool.
Note: * indicates significantly different (p<0.05) from the plastic scraper.
** indicates significantly different (p<0.01) form the plastic scraper.

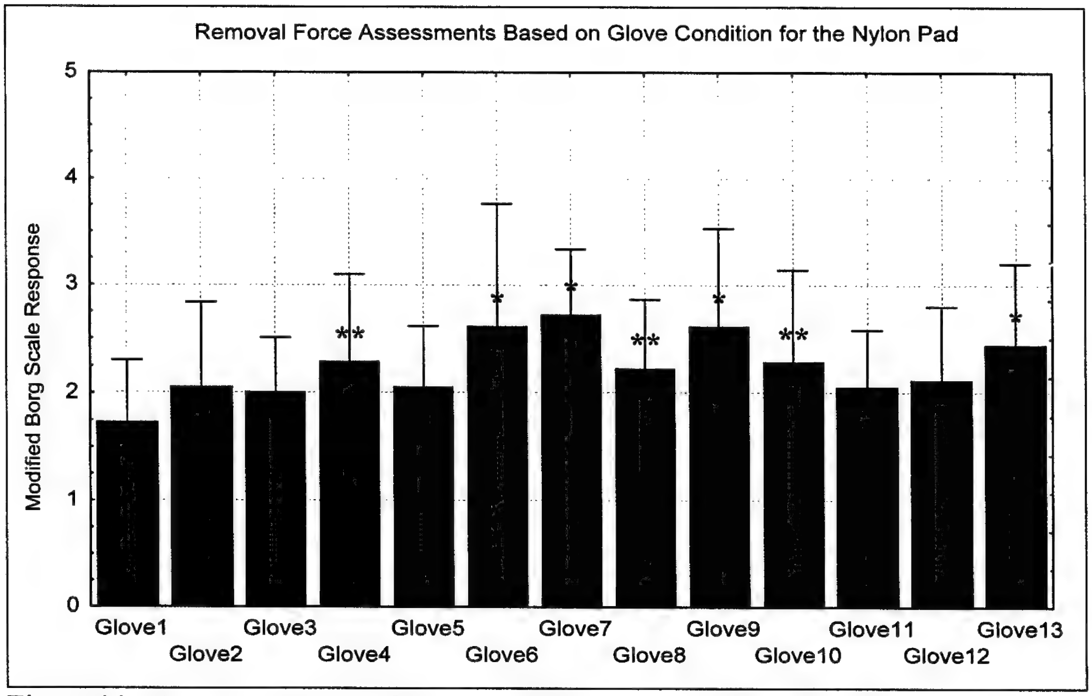

Figure 28. Average response for removal force using the modified Borg scale for removal trials with the nylon pad.
Note: * indicates significantly different (p<0.05) from Glove 1.
** indicates significantly different (p<0.01) form Glove 1.

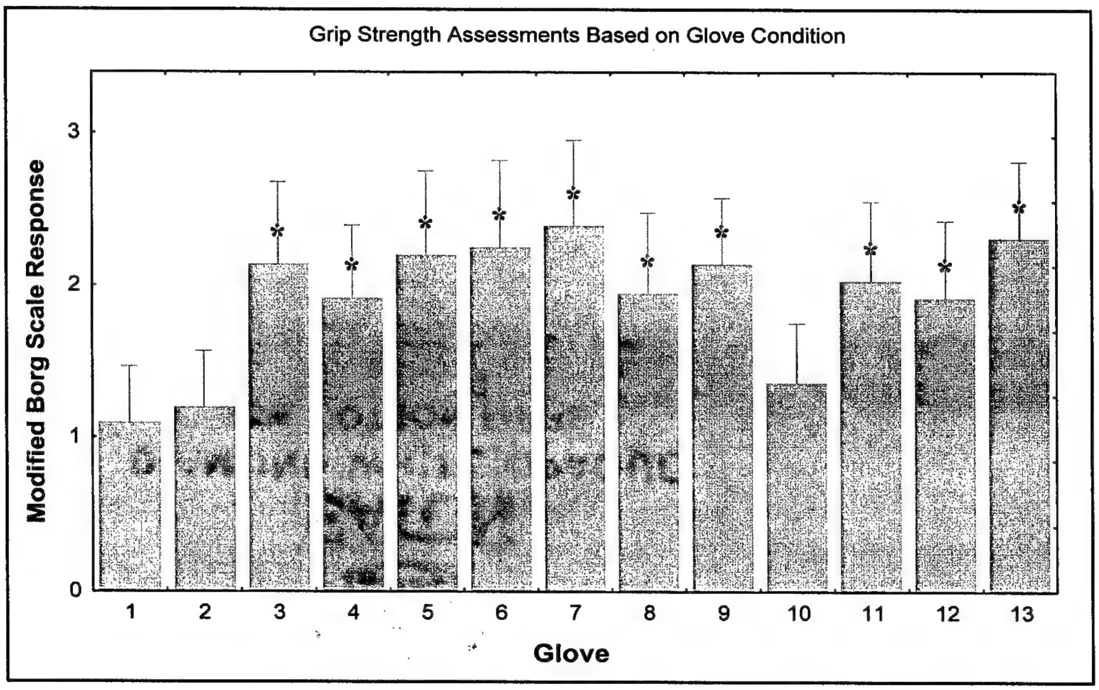

Figure 29. Average response using the modified Borg scale for grip strength requirements across both tools.
Note: * indicates significantly different (p<0.05) from Glove 1.

5.4. Data Correlations

5.4.1. Removal Force

The correlations between the average triceps activation level and the average removal force were examined for each tool. The correlations were 0.663 for the plastic scraper and 0.912 for the nylon pad ($p<0.05$, Figure 30 and 31).

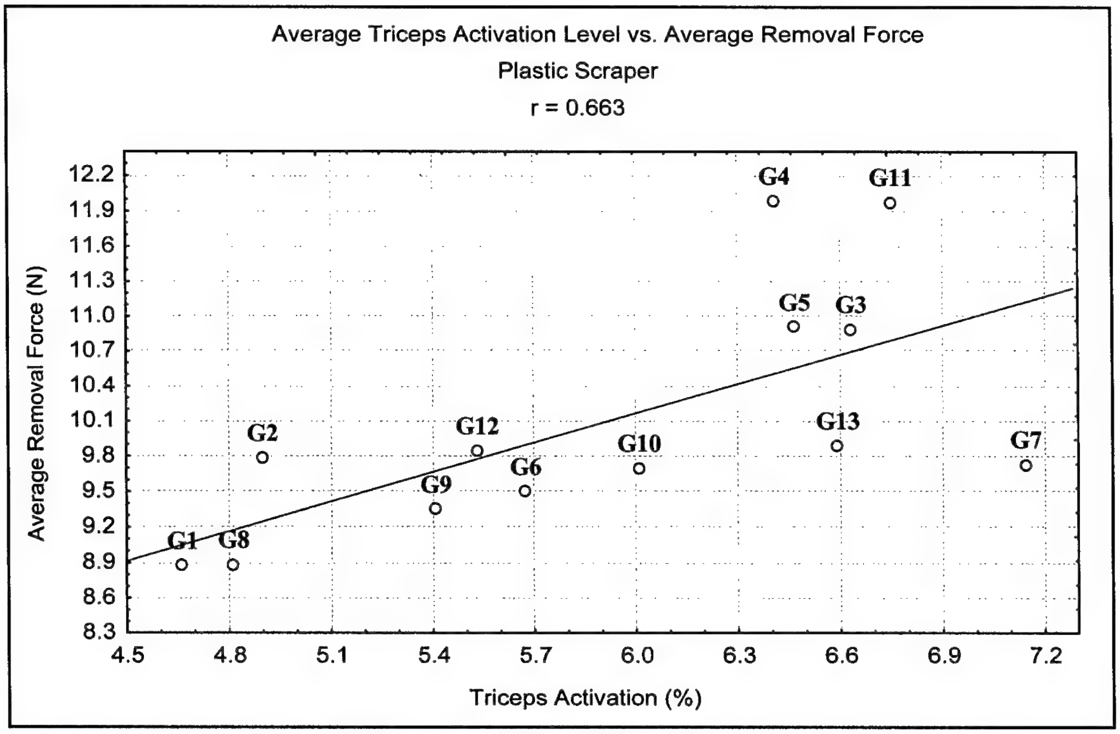

Figure 30. A comparison of the triceps activation percentage with the average removal force for the plastic scraper.

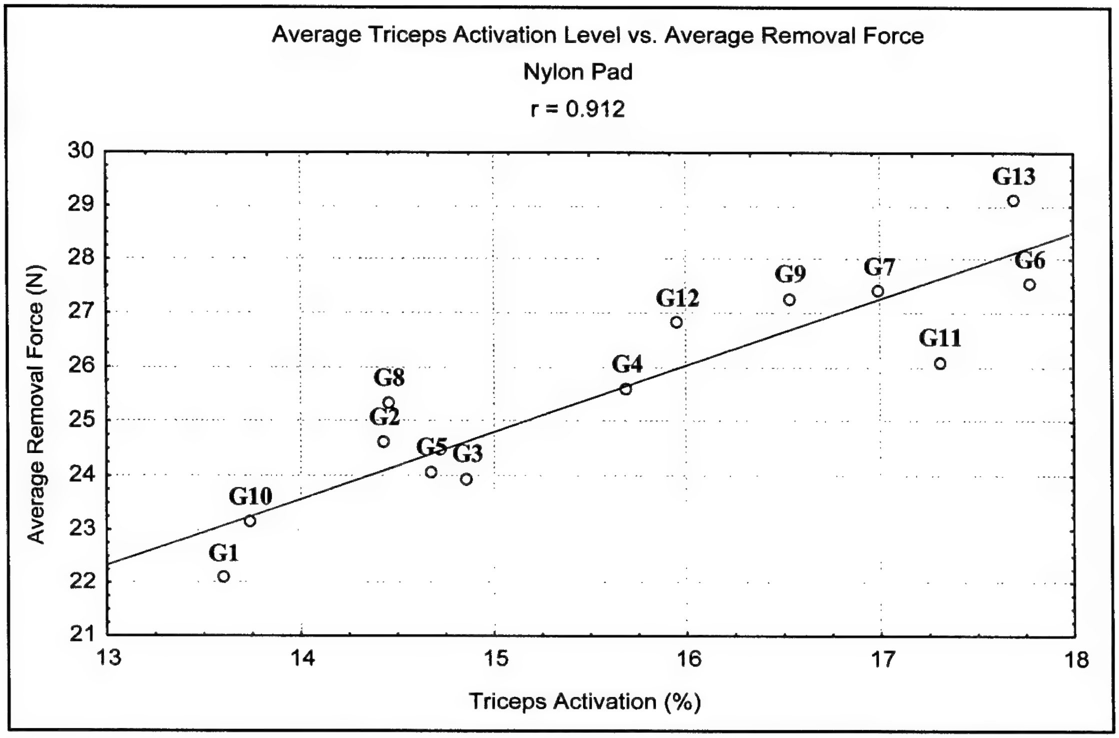

Figure 31. A comparison of the triceps activation percentage with the average removal force for the nylon pad.

The correlations between the average removal force and the average subject assessment of their exertions were also examined. The correlations between these two dependent variables were 0.167 ($p = 0.586$, Figure 32) for the plastic scraper and 0.760 ($p < 0.05$, Figure 33) for the nylon pad.

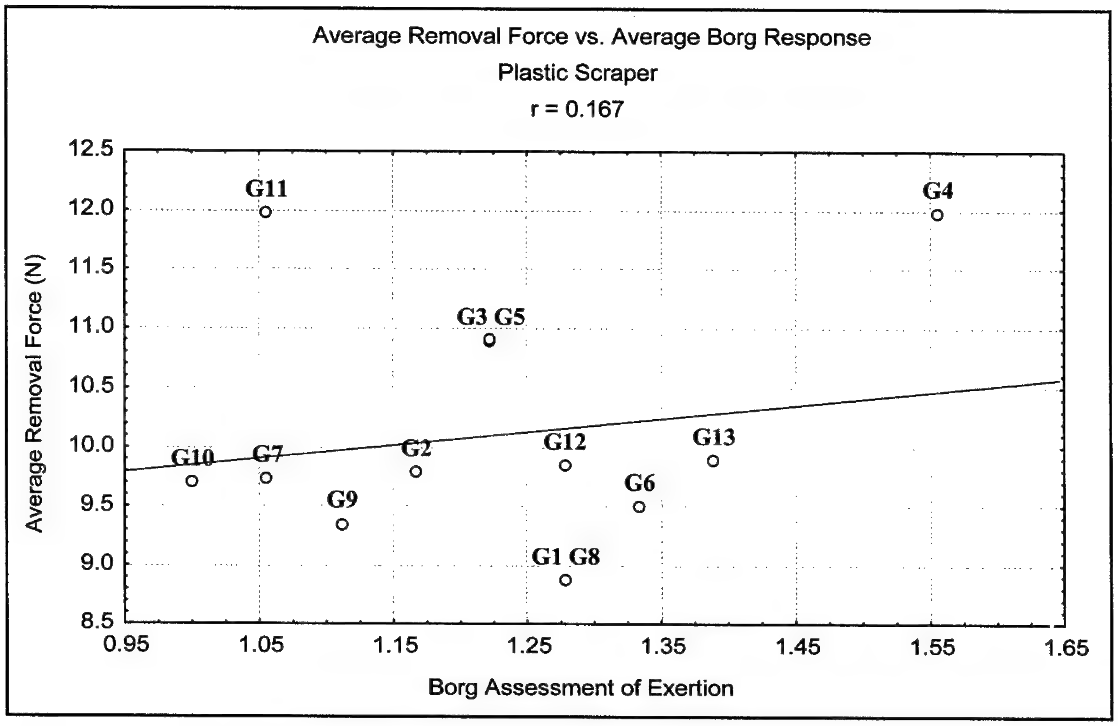

Figure 32. A comparison of the average removal force with the Borg assessments of the required exertion for the plastic scraper.

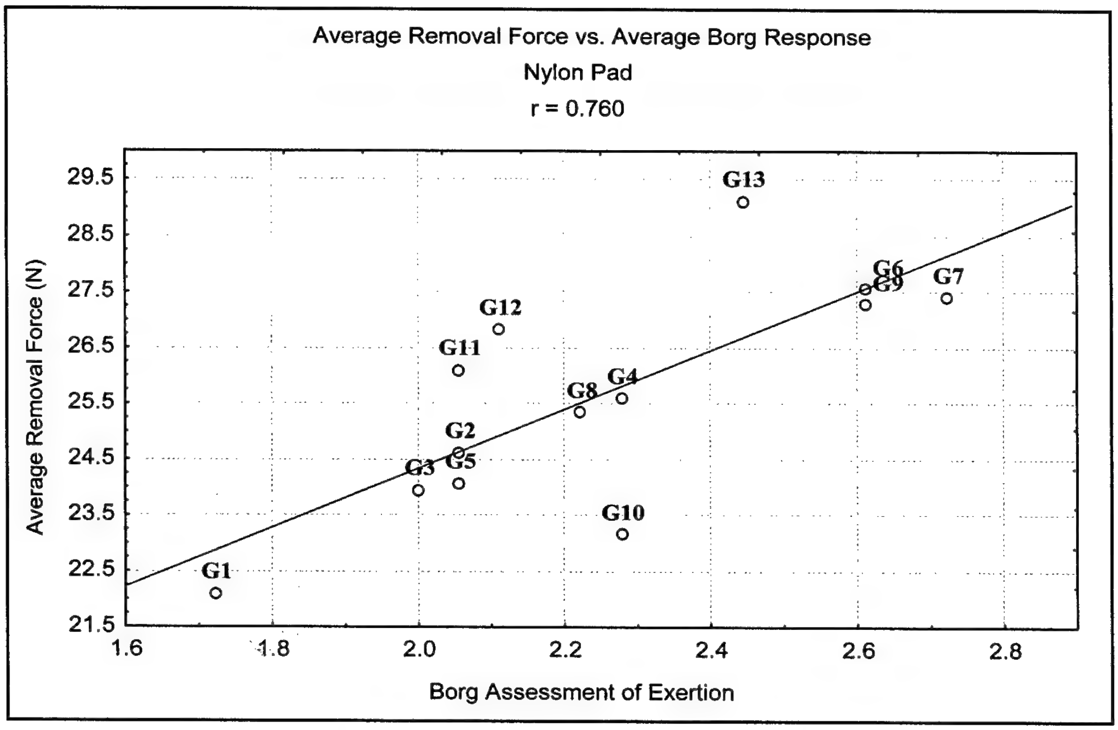

Figure 33. A comparison of the average removal force with the Borg assessments of the required exertion for the nylon pad.

5.4.2. Grip Strength

The correlation between the average assessment of grip strength and the average activation level of the finger flexors was also investigated. The correlation for the static flexor activation levels was 0.568 ($p<0.05$, Figure 34) and the correlation for the dynamic flexor activation levels was 0.678 ($p<0.05$, Figure 35).

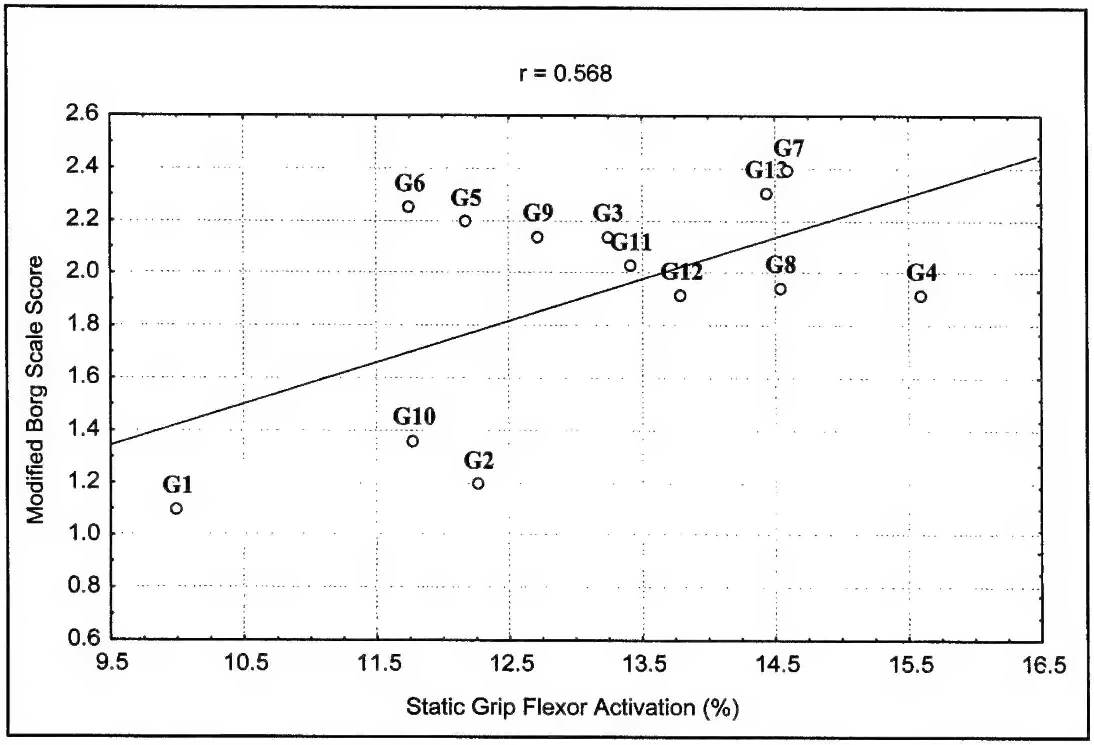

Figure 34. A comparison of the average flexor activation level during static grip time periods with the Borg assessments of required grip strength.

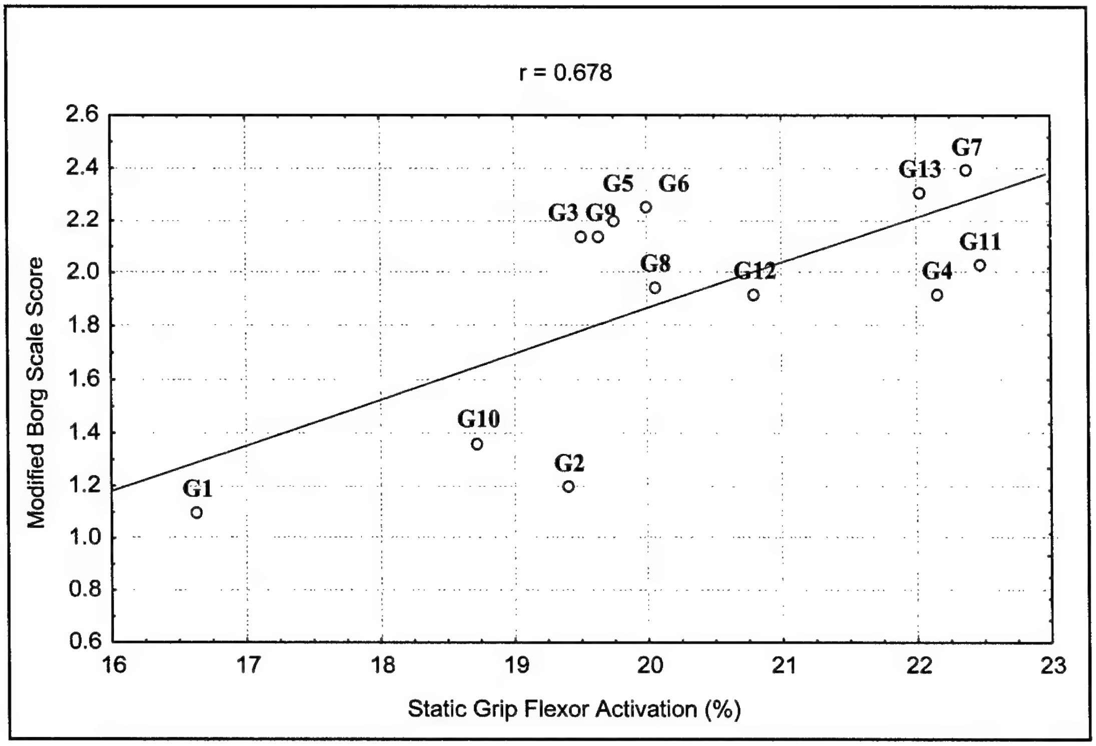

Figure 35. A comparison of the average flexor activation level active removal time periods with the Borg assessments of required grip strength.

5.4.3. Glove Thickness

The final set of correlation analyses conducted was a comparison of the glove thickness for the nitrile gloves (excluding the z-grip glove) with the average removal force, average static flexor activation, average dynamic flexor activation, and average assessment of grip strength. When a glove condition included the glove liner, the thickness of the liner (2.7 mils) was added to the thickness of the glove. The correlations for the glove thickness with the average removal force were 0.205 ($p=0.66$, Figure 36) for the plastic scraper and 0.860 ($p<0.05$, Figure 37) for the nylon pad. The correlations for the glove thickness and the flexor activation levels were 0.512 ($p=0.24$, Figure 38) for the static flexor values and 0.774 ($p<0.05$, Figure 39)

for the dynamic flexor values. Finally, the correlation for glove thickness and average assessment of required grip strength was 0.871 ($p<0.05$, Figure 40).

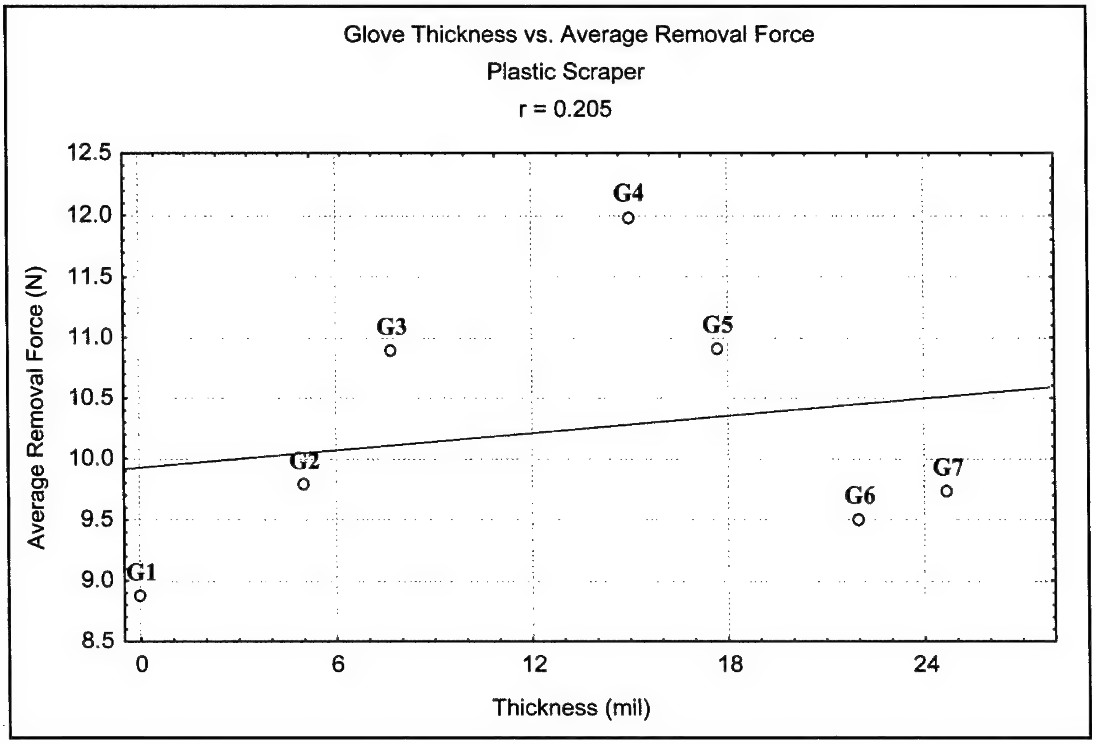

Figure 36. A comparison of glove thickness with the average removal force for the plastic scraper.

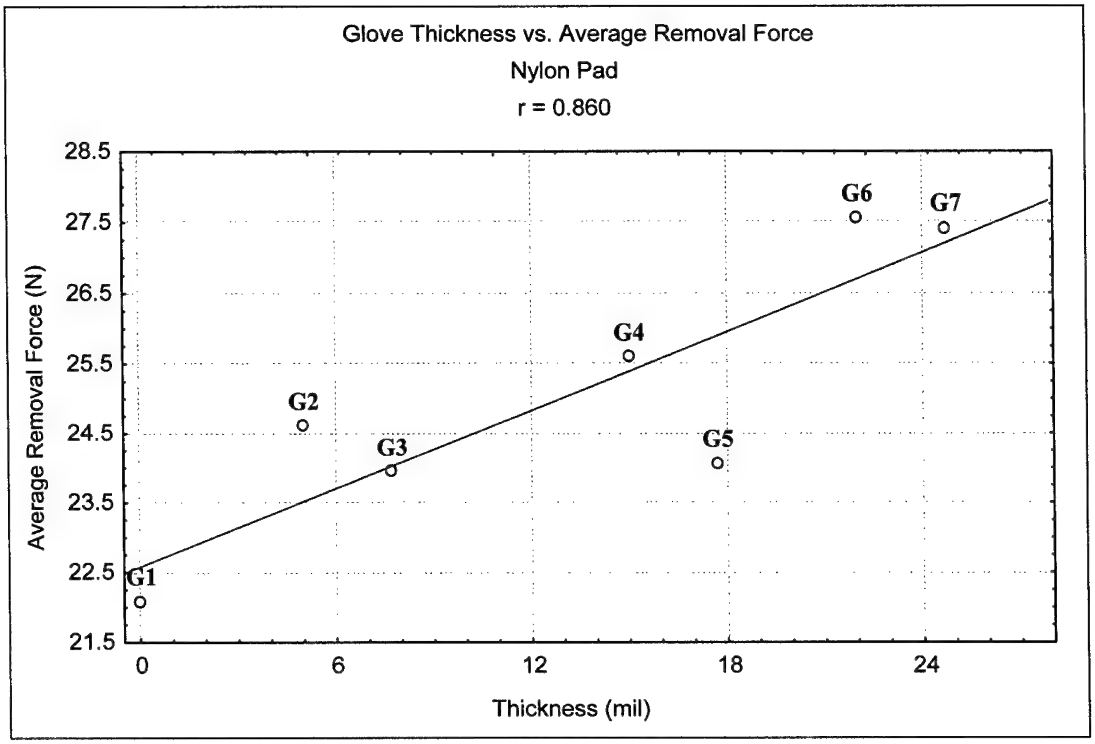

Figure 37. A comparison of glove thickness with the average removal force for the nylon pad.

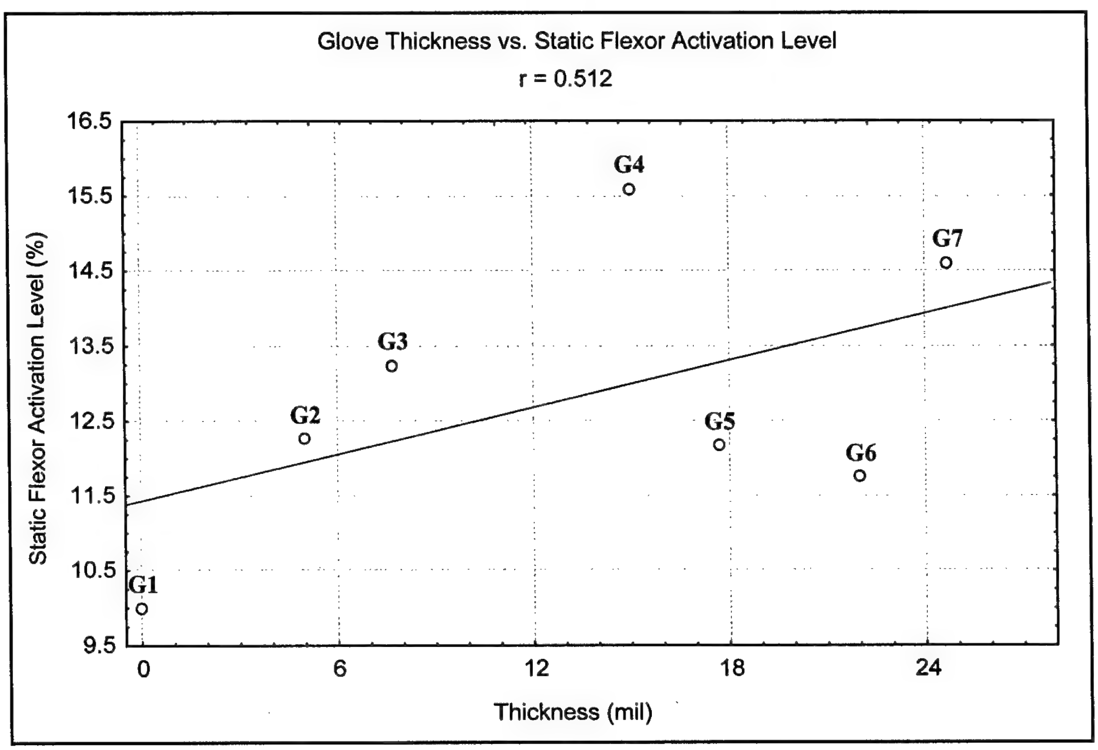

Figure 38. A comparison of glove thickness to finger flexor activation levels during the static grip time periods.

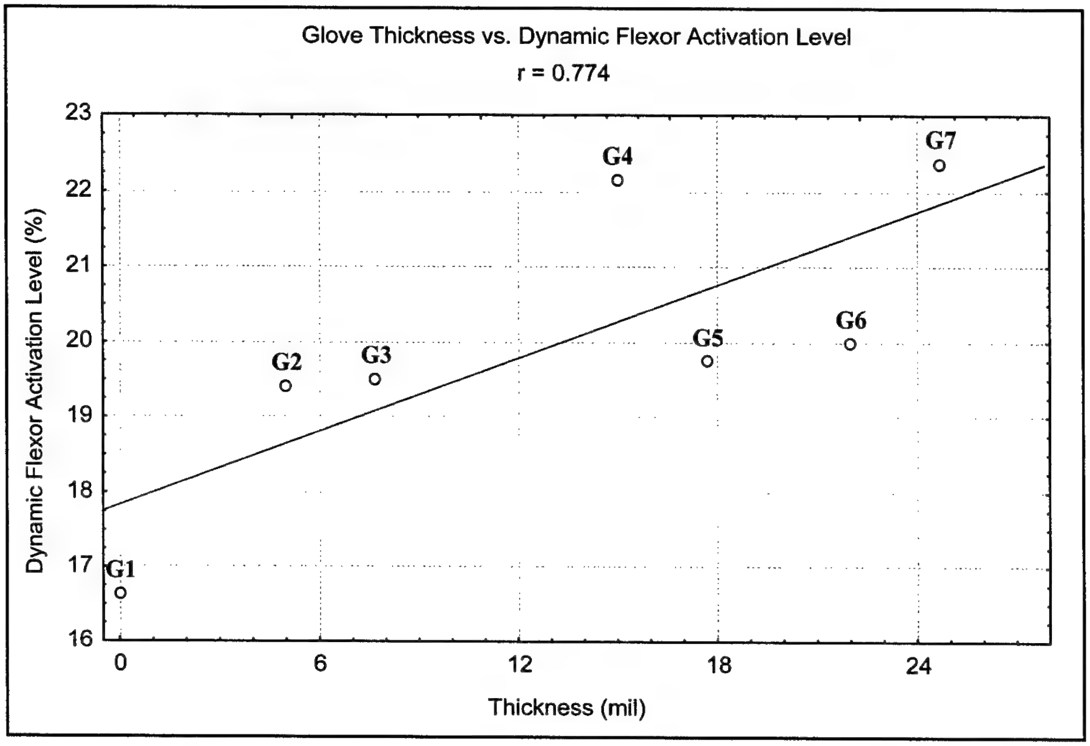

Figure 39. A comparison of glove thickness to finger flexor activation levels during the active removal time periods.

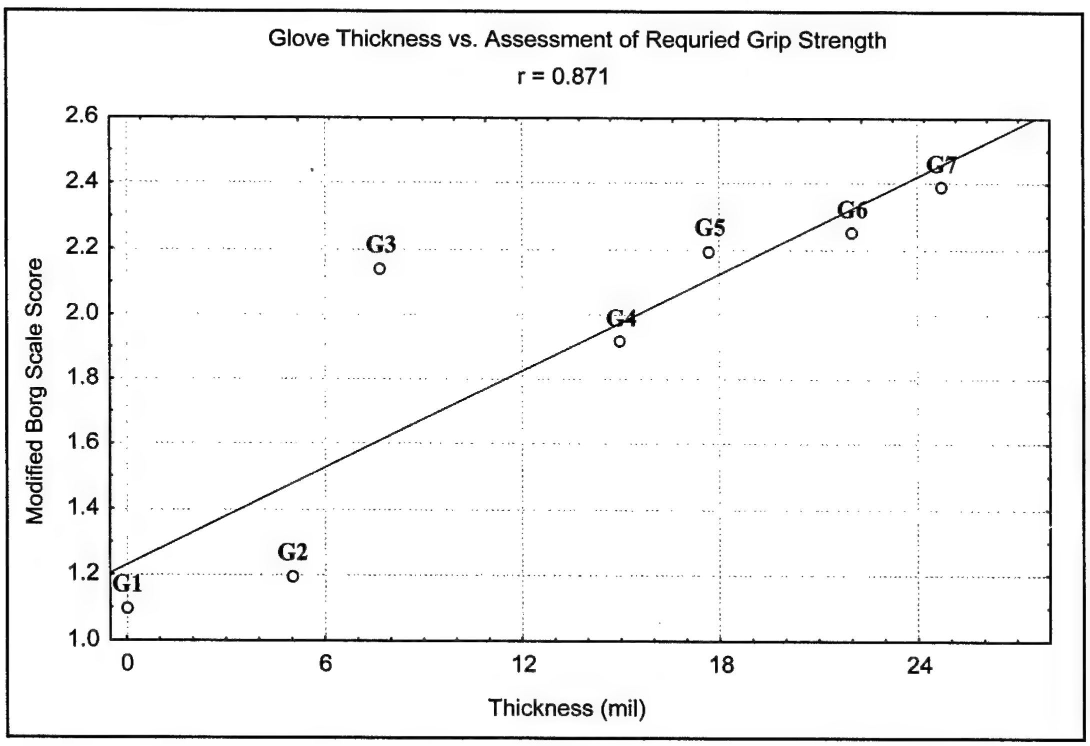

Figure 40. A comparison of glove thickness with subject assessment of required grip strength on the modified Borg scale.

5.5. Removal Times

The removal times for the experimental trials were defined as the amount of time between the start of the first removal impulse to the end of the final removal impulse. MANOVA analyses (Table 10) revealed that tool type was a significant main effect, but glove condition was not. The average removal times for trials with the plastic scraper (Figure 41) and the nylon pad (Figure 42) based on the glove condition are presented below.

Table 10. MANOVA results for removal time data

Effect	DOF Effect	Mean Square Effect	DOF Error	Mean Square Error	F	p-value
Tool	1	117.91	7	8.58	13.74	**0.0076**
Glove	12	0.092	84	0.30	0.311	0.99
GloveXTool	12	0.24	84	0.29	0.803	0.65

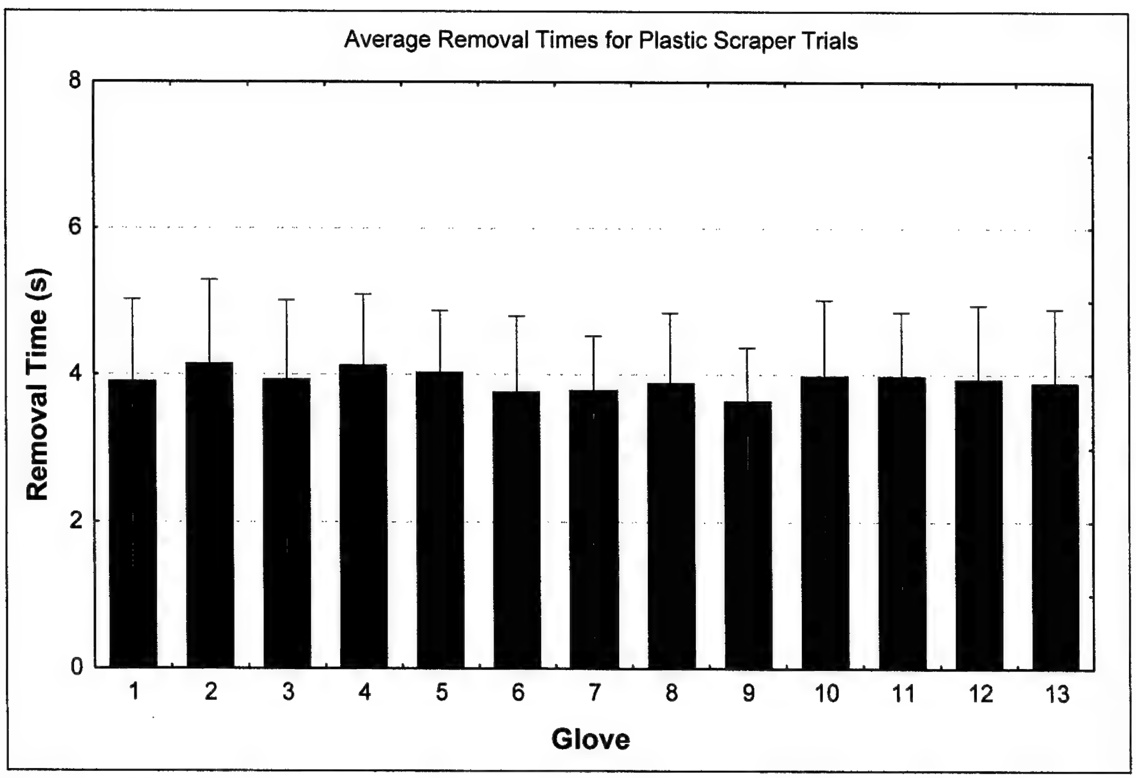

Figure 41. Average removal times for removing a single painted section with the plastic scraper.

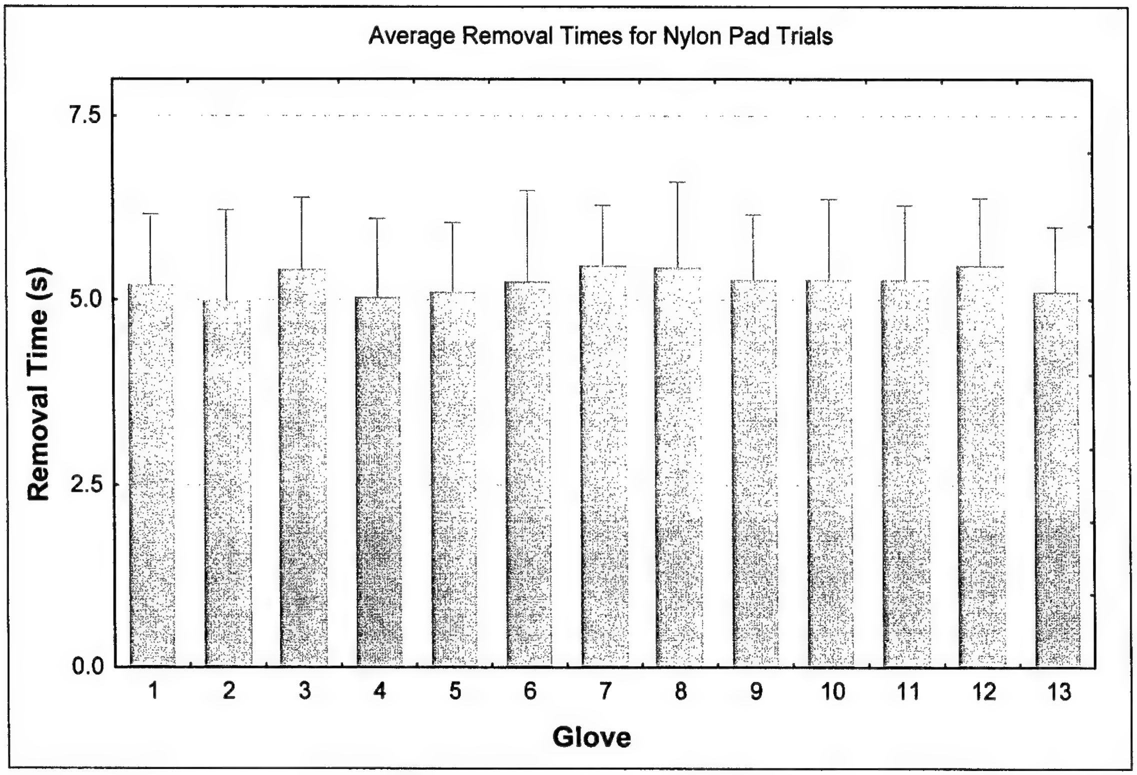

Figure 42. Average removal times for removing a single painted section with the nylon pad.

VI. Discussion

A main point of this experiment was to investigate how gloves affect workers who perform highly repetitive tasks that require sub-maximal exertions. It has been theorized that highly repetitive tasks, which typically require workers to use lower muscle activation levels, are overworking the few and smaller muscles that are recruited for these types of tasks (Stock 1991). Tasks of this nature are believed to have greatly contributed to the late 1980's surge in reported muscle, tendon, or nerve entrapment type disorders of the upper extremities (NRC 2001).

In this experiment, the average activation levels for the muscles of interest were below 25% of a maximum voluntary contraction (MVC). More specifically, the

average static finger flexor activation levels ranged (across all subjects) from 10 to 16% of MVC and the average triceps activation levels ranged from 4 to 18% of MVC. The dynamic flexors activation levels had the highest activation levels and they ranged from 16 to 23% MVC. These results revealed that this coating removal task would involve worker exertions that were on the highly sloped portion of the exertion-muscle endurance time curve. As discussed in the background section, small (1-5% MVC) increases in exertion levels result in much larger decreases with muscle endurance times when on this portion of the curve. Thus, since muscle fatigue is believed to be a reason for the development of MSD's, factors that can contribute to even small increases in muscle activation levels are important to understand.

6.1. Removal Forces

The data revealed that the average removal force for the nylon pad was over 2.5 times greater (Figure 11) than it was for the plastic scraper. One of the goals of this study was to see if the same trends existed even when there were different exertion level requirements from the subjects; thus, this finding confirmed that the experimental design sufficiently addressed this concern.

The data revealed that the glove conditions also had a significant effect (Figure 12) on the removal forces. All of the glove conditions had a higher removal force requirements than the barehanded condition (Glove 1) and most of these forces were found to be significantly different (minimum of $p<0.1$) from the barehanded condition. Only two glove conditions were not found to be significantly different from the barehanded condition and they were the medium thickness z-grip nitrile glove (Glove 8) and the thin latex glove (Glove 10). Thus, the data support a general

trend that wearing gloves caused the subjects to use higher forces when compared to the forces used in a barehanded condition.

The MANOVA analysis also revealed that there was a significant toolxglove interaction effect (Figure 13). Since the gloves conditions did not have the same effect on each tool, the glove effect on each tool was examined separately.

6.1.1. Plastic Scraper Removal Forces

For the plastic scraper, the vector-summation of the removal forces for glove conditions 3, 4, 5 and 11 were found to be significantly different than the barehanded condition (Figure 14). ANOVA analysis revealed that glove condition was not a significant main effect for the peak removal forces; however, this may have been caused by higher variability in peak removal forces when compared to the variability in average removal forces (Figure 14). Additional analyses of for the average shear (Figure 16) and normal (Figure 18) removal forces revealed that the same glove conditions were consistently different from the barehanded condition and glove condition was not a significant main effect for either the peak shear or the peak normal forces.

The consistent findings for the vector sum of the removal forces with the peak and the shear forces indicated that the subjects were fairly uniform with their removal techniques during data collection. This implied that the subjects did have enough practice trials with the plastic scraper prior to data collection. To confirm that the subjects used approximately the same technique for all removal trials, the shear and normal force were examined as a percentage of the vector sum of the forces (Figure 20). Since no significant differences were found between the 13 glove conditions, it

was concluded that the glove conditions did not cause the subjects to make major adjustments to their removal techniques other than an increase in the removal forces they used.

A poor correlation (r = 0.167, Figure 32) was found between the subjects' self-assessments of the removal forces and the measured average removal forces. This indicated that the subjects were mostly unable to detect any differences in applied forces when the plastic scraper was used. The overall range of the average modified Borg scale scores was 1.00 (Glove 10) - 1.56 (Glove 4). Since the average removal forces ranged from 8.87 N (Glove 1) - 11.98 N (Glove 4), it does seem that the subjects were able to correctly identify that the removal forces were low, but they did not clearly notice any force requirements differences when wearing the various gloves.

Although the correlation between these two variables was low, a high correlation would have been surprising for two reasons. The first and most important reason was the force data showed that there were only a few significant differences in the force requirements between the glove conditions. The second reason was likely related to the very low removal forces. A person ability to effectively use subjective assessments to quantify their perceived exertions is poor when at extremely light or extremely hard exertion levels (Borg 1998). Since none of the glove conditions had an average removal force over 12 N, it seems likely that the subjects were working in an extremely light exertion range where the value of self-assessments is poor.

The subjects did correctly identify Glove 4 as the condition that required the highest removal forces with the modified Borg scale scores, but this does not seem to

be a key finding. Glove 11 had nearly the same average removal forces as Glove 4 (11.97 N for Glove 11 and 11.98 N for Glove 4), but Glove 11 had the second lowest score (tied with Glove 7 @ 1.06) in the subjective assessments. This indicates that the subjects were not likely close to a minimum or a threshold-level of force differences that allowed them to clearly distinguish Glove 4 as the glove condition that required the highest removal forces. Similar observations exist throughout the data sets and these observations are clearly reflected by the poor correlation value of 0.167.

6.1.2. Nylon Pad Removal Forces

For the nylon pad, the vector-summation of the removal forces for glove conditions 4, 6, 7, 8, 9, 11, 12, and 13 were found to be significantly different than the barehanded conditions (Figure 15). The peak forces for glove conditions 6, 7, 8, 9, 11, 12, and 13 were also found to be significantly different from the barehanded condition (Figure 15). Further analysis of the force components revealed that the same glove conditions were significantly different from the barehanded condition for both the average/peak shear (Figure 17) and the average/peak normal (Figure 19) removal forces. Additionally, the average shear force for glove condition 2 and the peak normal force for glove condition 4 were found to be borderline ($p<0.1$) significantly different values.

Since there were two minor differences in which gloves conditions were significantly different from the barehanded condition, it was possible that the glove conditions were causing the subjects to change the removal technique (i.e. gloves caused them to trade off normal force for shear force or vice-versa). To evaluate this

possibility, the shear and normal forces were again examined as percentages of the vector-summed forces (Figure 21). This analysis revealed that there were not any significant differences based on the glove conditions. This implied that the glove conditions did not cause the subjects to make major adjustments to their removal techniques other than increasing the removal forces that they used. It was then concluded that the two additional differences that were found when the shear and normal forces were examined were the result of statistical-borderline cases and did not indicate the subjects altered their removal technique when these two gloves were worn.

The correlation between the average removal forces and the average scores for the subjective assessments of perceived exertions was significant ($r = 0.760$, Figure 32). The overall range of the average modified Borg scale scores was 1.72 (Glove 1) to 2.72 (Glove 7) and the average removal forces ranged from 22.09 N (Glove 1) to 29.12 N (Glove 13). For the nylon pad, glove condition was a significant main effect for the subjective evaluations of the removal force; thus, it seems that the subjects were aware that the glove conditions affected their force outputs. The significant correlation between these two variables showed that subjects were frequently able to correctly determine which gloved conditions caused them to use higher forces.

6.1.3. Tool Comparison

After examining the removal forces for each tool separately, it was apparent that the glove conditions had a stronger affect on the removal forces for the nylon pad. Thus, it cannot be concluded that gloves had the same effect on each tool. A possible explanation for this finding is the plastic scraper provided an additional

feedback to the subjects when it was being used as the removal tool. This feedback may have been from the plastic blade itself.

The plastic scraper had a 6 cm flexible blade and the blade was very responsive to the removal forces being applied. As removal forces increased, more and more of the blade closest to the tip would flatten out and become parallel to the removal surface. Subjects could easily see this deformation when using this tool and they could probably 'feel' the additional elastic energy being stored as a result of the elastic deformation. Perhaps, since the plastic scraper provided more information to the subjects on their removal forces, the subjects found it easier to be more consistent with their removal forces when glove were worn.

One problem with this explanation that the plastic scraper provided additional feedback is that significant differences in peak forces were not present (Figure 14) when the plastic scraper was used. If subjects were using feedback from the blade to regulate their removal force, it would seem the blade's feedback mechanism would alert the subjects to when they were applying additional forces and the subjects would then correct their removal technique. If this were the case, different peak forces for the glove conditions would be expected. Since glove condition was not a significant main effect for the peak removal force for the plastic scraper, there is some question about this reasoning; however, it may be important to note that the variation in the peak removal force measurements was higher than any of the other force measurements. Since the differences in the average values for the peak removal forces look similar to the difference in the average removal force, the higher

variability in these measurements may be the reason why statistical significant findings were absent.

Another possibility for the difference in the glove condition effect between the two tools may have been related to the difference in force requirements. The plastic scraper only required an average removal force of 10.1 N across all glove conditions. Perhaps, this force requirement was so low that the subjects were not affected by the glove conditions. This could indicate that there is a minimum force requirement that must be surpassed in order to have a glove effect; however, this experiment was not designed to investigate a question of this nature.

The correlation between the average removal force and modified Borg scale scores was much better for the nylon pad than it was for the plastic scraper. This discrepancy between the two tools is probably best explained by the lack of significant differences for removal forces when the plastic scraper was used. The subjective evaluations also indicated that the subjects noticed a difference between the required removal forces between the two tools (Figure 27), which was consistent with the measured forces (Figure 11). It is not clear why the subjective evaluation were not very successful for the plastic scraper (limited differences in force requirements or the forces were below a force threshold where distinctions can be easily made); however, the data for the nylon pad indicated that subjective evaluations may be a valuable tool to help identify when gloves are requiring workers to use higher forces to perform a task.

One of the interesting findings was the lack of variability with the removal technique (Figures 20 and 21). When the shear and normal forces were compared as

a percentage of the vector-sum of the forces for each subject, the variability was far less than any of the other force measures. The lack of inter-subject variability provides evidence that finding the optimal removal technique for each tool required little practice. These findings provided more evidence that the experimental task was quickly learned by all of the subjects.

6.2. EMG Analysis

EMG analysis was used for two main purposes in this experiment. The first reason was to quantify the muscle activation levels needed for the physical exertions and the second purpose of this analysis was to quantify the grip forces. Unfortunately, a more direct evaluation of grip force was not possible for this experiment.

6.2.1. Removal Exertion Analysis

MANOVA analysis of the triceps EMG data during the active removal periods revealed that both the tool and the glove condition were significant main effects (Table 9). A further examination of the tool effect revealed that the triceps activation level was approximately 2.7 times higher for the nylon pad across all glove conditions (Figure 24). This finding was very consistent with the difference in average removal forces between the two tools (2.6 times higher, Figure 11).

In order to evaluate the glove effect on the triceps activation levels, the data were examined separately for each tool. This was done to be consistent with the analyses that were already performed on the removal forces. These analyses revealed that the triceps activation level was significantly different from the barehanded

condition for glove conditions 3, 4, 5, 7, 11, and 13 for the plastic scraper and for glove conditions 6, 7, 9, 11, and 13 for the nylon pad (Figure 26). These finding were mostly consistent with the differences found between the glove conditions for the average removal force (Figures 14 and 15) analyses.

For the plastic scraper, all of the glove conditions that required significantly greater average removal forces than the barehanded condition (i.e. glove conditions 3, 4, 5, and 11) were also found to have significantly higher triceps activation levels. However, an explanation for why glove conditions 7 and 13 were also found to have significantly different triceps activation levels was needed.

A review of the force data revealed that Glove 13 had the highest average removal force of the glove conditions that were not statistically different from the barehanded condition (Figure 14), so it was not that surprising that this glove condition also had significantly different triceps activation levels. Conversely, it was somewhat surprising that Glove 7 had the highest triceps activation, since its average removal force was similar to the barehanded condition's average removal force. This was the thickest glove condition used (thick nitrile glove with the chemical insert) and it was the only glove condition that indicated something unusual was happening with the removal forces for this tool. The triceps activation level for this Glove 7 was highest; thus, it was expected that Glove 7 would also have one of the higher force measurements. Since this was not the case, the data indicates that there was a loss of applied forces at the removal surface.

For the nylon pad, all of the conditions that had significantly different triceps activation levels were found to have significantly different average removal forces.

However, the removal force data determined that glove conditions 4, 8, and 12 also had significantly different average removal forces, but corresponding differences in triceps activation levels were not found. A closer look at the triceps activation levels revealed that conditions 4 and 12 were the two highest average triceps activation levels in the group of glove conditions that were not significantly different from the barehanded condition. Therefore, it was likely that the higher variability in the EMG data when compared to the force data was the reason for these two differences. Glove 8 was a borderline significant ($p<0.1$) case for the average removal forces, but this alone did not seem to be enough to explain why it had one of the lowest triceps activation levels and one of the highest average removal force measurement

Since there were two inconsistencies found with the force and triceps EMG data, these data sets were investigated further. The average removal force was plotted against the average triceps activation level for each tool (Figures 30 and 31). The result of these two plots indicated that the two data were fairly well correlated ($r = 0.7$ for the plastic scraper and $r = 0.9$ for the nylon pad). Although there were a few glove conditions that obvious lowered the correlation values, the overwhelming majority of the data points indicated that gloves were not directly causing an increase or decrease in the removal forces (i.e. a force enhancement/deterioration from the glove itself); rather, force increases and decreases could be explained by the subjects' exertion level. This indicated that the glove conditions were interfering with the subjects' ability to minimize the forces needed to perform the removal task. This was an interesting finding, because it provided evidence that the losses in haptic

sensitivity experienced when wearing gloves has a greater effect on force output than it does on grasping force.

The lack of significant findings (Table 8) for the biceps muscle was not surprising since this muscle was not really involved in the biomechanics behind the removal process. The EMG data from this muscle was mostly used to help determine the active/static grip time periods.

6.2.2. Finger flexor activation levels

The flexor EMG analysis occurred for two different time periods in the removal process. The first time period was the 'static grip force' period and this period consisted of the data points in-between the active removal exertions (Figure 9). The main advantage of looking at these periods in the EMG data was the activation levels of the other muscles in the forearm less influenced the data during these time periods. Since surface electrodes were used, the finger flexor data collected during the periods of active removal likely contain additional signals from the muscles near the finger flexors (the wrist flexors and the palmaris longus). During the static grip force time periods, though, activation of other muscles near the finger flexor electrode placement should have been minimized.

The inability to exactly determine the influence of the nearby muscles on the finger flexor signals was the major reason why the subjects' maximum grip EMG values (per tool) were used to normalize data from these time periods instead of the maximum finger flexion values. Since the subjects likely activated their wrist muscles when performing the maximum finger flexion exercise, this maximum EMG value was likely increased from the simultaneous activations of the surrounding

muscles. In fact, the maximum grip EMG values were always lower than the maximum flexion EMG values for all of the subjects tested. This finding confirmed that using the maximum grip EMG values instead of the maximum finger flexion values to normalize the static flexor activation levels was appropriate.

MANOVA analyses of the static grip forces revealed that the only the significant main effect was glove type (Table 4). It was somewhat surprising that tool type did not have an effect on the grip forces since the plastic handle seemed to have obvious frictional difference from the nylon pad. A possible explanation for this finding is that the nylon pad grip was more complex than the grip used for the plastic scraper. This may also explain why the static extensor activation levels (Figure 23) were higher for the nylon pad.

Post hoc analyses on the static flexor values revealed that glove conditions 3, 4, 7, 8, 9, 11, 12, and 13 were significantly different than the barehanded condition (Figure 22). The highest grip force was 15.6% of MVC (Glove 4) and represented an increase in flexor activation of over 55% when compared to the barehanded condition. Even though not all of the gloves were found to be associated with significantly higher grip forces, the general trend clearly indicated that the grip forces increased when gloves were worn. This finding provides strong evidence that gloved workers are at an increased risk to MSDs when compared to barehanded worker performing a similar task, especially when the task is performed over long durations.

For the dynamic time periods, glove condition was again the only significant main effect for the finger flexors (Table 6) and no significant main effects were found for the extensors (Table 7). For the dynamic flexors, *post hoc* analyses of the glove

effect revealed that all of the glove conditions except for Glove 10 (thin latex) were significantly higher than the barehanded condition (Figure 24). As with the static flexors, there was a clear trend showing wearing gloves increased the activation levels of the muscles in the forearm.

As previously discussed, the dynamic flexor activation levels shown are not representative of only increases in flexor activation levels, though. Since force differences were also found for the gloved conditions, some of the increases found for the dynamic flexors are likely related to increased activation levels of the wrist flexor muscles. In order to maintain the same arm position at higher force levels, the subjects needed to increase their wrist flexors activation levels. Thus, some of the EMG signal from the increased wrist flexor muscles activation was likely included in the finger flexor data because of the close proximity between these muscle groups. Although the data do not show only the increases in the finger flexor activation, the data clearly show that the level of forearm muscle activation as a whole is greater for gloved workers. This finding also indicates that a worker's risk for MSDs is likely higher when the gloves are worn.

The data for the subjective evaluations of grip strength revealed there was a significant difference based on the tool used (Figure 27). The average modified Borg score for the nylon pad was higher than the plastic scraper when averaged over all glove conditions. The higher score for the nylon pad was most likely caused by this tool requiring a more complex grip and necessitating higher removal forces. Glove condition was also found to have a significant main effect. *Post hoc* analyses revealed that all of the glove conditions except for Glove 2 (thin nitrile) and Glove 10

(thin latex) were significantly higher than the barehanded score. With the exception of the lower score for Glove 2, this data set seemed to correspond well with the dynamic flexor findings.

To further investigate the subjective evaluations of grip strength, the correlation between the grip strength score and the static and dynamic flexor data was examined (Figures 34 and 35). As indicated above, the correlation with the dynamic flexor data ($r = 0.68$) was slightly better than the correlation with the static flexor data ($r = 0.57$), but both correlations were significant. It may also be important to MSD risk that the subjects thought that their grip strength was higher when gloves were worn, but the exact impact of psychophysical factors such as this are still unclear (NRC 2001).

6.3. Glove Effects

6.3.1. Glove Thickness

To determine if glove thickness had an effect on the subjects' removal forces, the removal forces for the nitrile gloves were examined. Only the nitrile gloves were examined to negate the possibility of a material effect. Additionally, the z-grip nitrile gloves (Glove 8 and 9) were also not included in these analyses.

The correlation between glove thickness and average removal force for the plastic scraper was poor ($r=0.21$, Figure 36). This was not surprising since the glove conditions did not have a very strong effect on the removal forces for this tool; however, the correlation between these two variables was much better for the nylon pad ($r=0.87$, Figure 37). This is likely a good indication that glove thickness may be

important to force outputs since the nylon pad had a stronger relationship between the glove conditions and the removal forces.

To determine if glove thickness had an effect on the subjects' grip forces, the dynamic and static flexor activation levels were examined. Again, only the nitrile gloves (Gloves 1-7) were examined, but the data were collapsed over both tools. This was done because the flexor analyses showed that tool was not a significant main effect for these measures.

The data for the static flexors showed that glove thickness was slightly correlated with the static flexor activation levels ($r=0.51$, Figure 38); however, this correlation was not significant ($p=0.24$). On the other hand, the correlation for the dynamic flexors ($r=0.77$, Figure 39) was higher and significant. This, though, could be because the dynamic flexor values were also affected by increases in the removal forces. Since removal forces were already shown to have a good correlation with glove thickness, the correlation value for the dynamic flexors likely increased at least partially, if not completely, because of the thickness-removal force relationship presented above. Thus, a more direct method of evaluating the grip forces is needed to better understand the grip forces during the active removal periods.

It was also interesting that the subjective evaluations of grip force were better correlated with glove thickness ($r=0.87$, Figure 40) than either of the EMG evaluations of grip strength. Although this was not specifically evaluated, it was very likely that all of the subjects recognized the thickness differences between the gloves. The high correlation found between glove thickness and grip strength evaluation is

another finding that indicates psychophysical factors are also important when gloves are donned.

The relationships between glove thickness, grip forces and removal forces indicate that loss of haptic sensitivity did affect motor output. Interestingly, this loss in haptic sensitivity had a stronger effect on the removal forces than the grip forces. This indicates that, in future studies, the glove effect on motor output should be examined at a task output level along with what is occurring at the glove interface.

6.3.2. Glove Material and Removal Forces

Three different materials were examined in this experiment to help determine if glove material was important to ergonomic risk factors. In order to examine the effect of material type, the likely selected thicknesses for butyl and latex over-gloves were tested along with the nitrile gloves. Since glove thickness seemed to have an effect, the butyl and latex gloves were only compared to the nitrile gloves of equal thickness. Complete *post hoc* analyses tables for key dependent variables are included in Appendix E.

The removal force when the medium thickness butyl gloves (Glove 12) were worn was 9.85 N for the plastic scraper removal trials. This value was lower than the medium thickness nitrile gloves (Glove 4), which was 11.98 N and this difference was determined to be a borderline significant difference ($p<0.1$, Appendix E-1). The removal trials with the nylon pad found that the removal forces for Glove 12 were higher (26.83 N to 25.60 N) than removal forces for Glove 4, but this difference was not significant ($p=0.46$, Appendix E-2). A similar comparison was made for the thin latex glove (Glove 10) and the thin nitrile glove (Glove 2). This comparison revealed

that the removal forces were lower for Glove 10 for both tools, but these differences were not significant (Plastic scraper: 9.70 N to 9.79 N; Nylon Pad 23.15 N to 24.62 N).

Although the plastic scraper removal forces for Glove 4 and Glove 12 were significantly different, concluding that nitrile gloves cause higher force outputs is not strongly supported by the data set as a whole. As discussed above, the data showed that the glove conditions did not affect the removal forces for the plastic scraper as strongly as they did for the nylon pad. This along with the fact the nylon pad showed an opposite trend (i.e. higher removal forces when the butyl glove was worn) raises some questions about this finding. Further, an examination of the removal forces for Glove 12 and Glove 13 (butyl gloves with the chemical insert) for the nylon pad trials reveals that these conditions had two of the highest values for removal forces. In fact, Glove 13 had the highest removal forces and was significantly different from both Gloves 4 and 5. Therefore, it would seem the data much more strongly support the conclusion that butyl gloves result in workers applying higher forces than equivalent thickness nitrile gloves.

The comparison between the latex gloves and the nitrile gloves revealed that the latex gloves tended to have lower force requirements. The plastic scraper trials yielded nearly identical removal forces for these two glove types, but the difference for the nylon pad has some indications that there might be a more significant difference between the two glove types. For the nylon pad trials, Glove 10 had the second lowest removal forces (Glove 1-barehanded was the lowest) and tended to be different from all of the other glove conditions. In other words, Glove 10 was more

similar to the barehanded condition than Glove 2 was to the barehanded condition. This does imply that latex might be better than nitrile at reducing excess removal forces, but more data are needed to confirm this finding.

6.3.3. Glove Material and Grip Forces

To determine if glove material had an effect on the grip forces, a comparison similar to the one done for removal forces was performed. Glove 4 had the highest value for static flexor EMG, but this value was not significantly different from Glove 12 (Appendix E-3). The dynamic flexor comparison also showed that Glove 4 had higher, but not significantly different grip forces (Appendix E-4). Thus, there is some support that nitrile gloves tended to require higher grip forces than butyl gloves, but the evidence is inconclusive. Although friction coefficients were not estimated in this experiment, it did seem that the slick butyl gloves must of had lower coefficient of friction than the rough nitrile gloves. This may provide some indirect evidence that nitrile gloves reduce grip force to a higher degree than butyl gloves, but this evaluation was not specifically conducted in this experiment.

A comparison of the flexor activation levels between Gloves 2 and 10 revealed that the latex gloves required lower grip forces, but these differences were not significant. The *post hoc* analyses for these gloves were very similar and there were no obvious differences between the frictional characteristics of these gloves. Thus, it would seem that any glove induced grip force reduction is similar between these two material types. It is also possible that a detectable difference between these gloves was not found because of the extremely thin thickness that was evaluated. In

other words, a comparison of medium thickness latex and nitrile gloves might reveal different results.

6.3.4. Chemical Insert Effects

To evaluate the effect the chemical inserts had on the removal and grip forces, the *post hoc* analyses were again examined (Appendix E). For the removal forces, both tools showed a significant increase in removal forces when the latex glove was used with the chemical insert. For all of the other over-gloves, the use of a chemical insert did not seem to have a major effect. If the force increases were mostly caused by a loss in haptic sensitivity, it seems the chemical inserts neutralize the advantage latex has over the other glove types in minimizing this loss.

The effect that the chemical inserts had on subject grip strength is more complicated. For the medium thickness nitrile gloves, the inserts significantly lowered the subjects' static flexor activity, but the inserts significantly increased the subjects' static flexor activity when they wore thick nitrile gloves. The general trend that was determined above was glove thickness increased flexor activation levels; thus, it would seem that the decrease found for the medium thickness gloves was an anomaly. Additionally, out of the four (Glove 2, 4, 5, and 10) glove conditions that were not found to be different from Glove 1's static EMG value, only one of them (Glove 5) did not have a chemical insert. This seems to indicate that the chemical inserts may cause a subtle increase in grip strength. Thus, there are some indications that using a chemical insert will cause higher flexor activation levels, but more data are needed to confirm this finding.

6.3.5. Z-grip Effect

The purpose of the z-grip texture was to improve the grip characteristics of this nitrile glove (Glove 8 and 9). A comparison was made between the static flexor activation levels for the z-grip gloves and the regular grip nitrile glove of equal thickness (Gloves 4 and 5) and it showed these gloves required similar activation levels (Appendix E-3). This indicates that the grip characteristics were not changed sufficiently to have an impact on MSD risk factors in this case. However, if the objects held by the subjects were smaller or different in some other aspect (e.g., wet or oily objects), the results may have been different.

6.5. Limitations and Future Work

The fact that this experiment had only nine subjects was the main limitation for the information that was gathered. A higher number of subjects probably would have improved the significance levels found in the statistical analyses. Despite this limitation, the data showed that there were some important differences when gloves were worn. Another limitation for this experiment was the inability to have a more direct evaluation of the subjects grip strength. This would have been valuable for determining differences between static and dynamic grip strength. Finally, the data showed that glove use was related to increased muscle activation levels, but how important these increases are to MSD risk is unclear. More research is needed in defining how closely muscle activation levels are tied to MSD risk. Although higher forces are believed to be associated with higher MSD risks, the exact increase in MSD risk when finger flexor activation increases by 5% is not clear.

VII. Conclusions

The objective of this experiment was to determine how glove use affects workers who are performing a task that requires submaximal exertions. Previous research efforts have provided some indications that motor performance is altered when gloves are worn, but more information was needed to fully understand how motor performance changes, especially during submaximal exertions. To investigate this situation, removal forces and muscles activation levels were monitored for nine subjects while they performed a simple coating removal task. Force and EMG data were gathered for thirteen different glove combinations and two different removal tools while the subjects performed the coating removal task. From the information that was gathered, several conclusions were drawn.

- When compared to the barehanded condition, wearing gloves caused the subjects to increase their removal forces.
- Wearing gloves did not cause the subjects to change their removal technique except for an increase in the removal forces they used.
- Wearing gloves caused subjects to increase the activation levels of their finger flexor muscles.
- Wearing gloves caused the forearm muscles to have higher activation levels during the removal task.
- Subjective evaluations can be used to indicate when gloves might be causing increases in grip strength and removal forces.
- There was a good correlation between higher applied forces and thicker gloves.

- There was some evidence that glove material has an effect on removal and grip forces.
- Thin (5 mil) latex gloves were most similar to the barehanded removal and grip forces.
- Using a chemical insert under a thin latex glove eliminates the advantage this glove has over other glove types in minimizing additional removal and grip forces.

The information gathered from this experiment provided some insight to how physical exertions change when workers are required to wear gloves. Knowing that gloves can cause differences in a worker's motor performance is likely important to future research that is focused on establishing dose-response relationships for MSDs. This information can also be used to help with proper glove selection for industrial workers that perform highly-repetitive, long-duration tasks.

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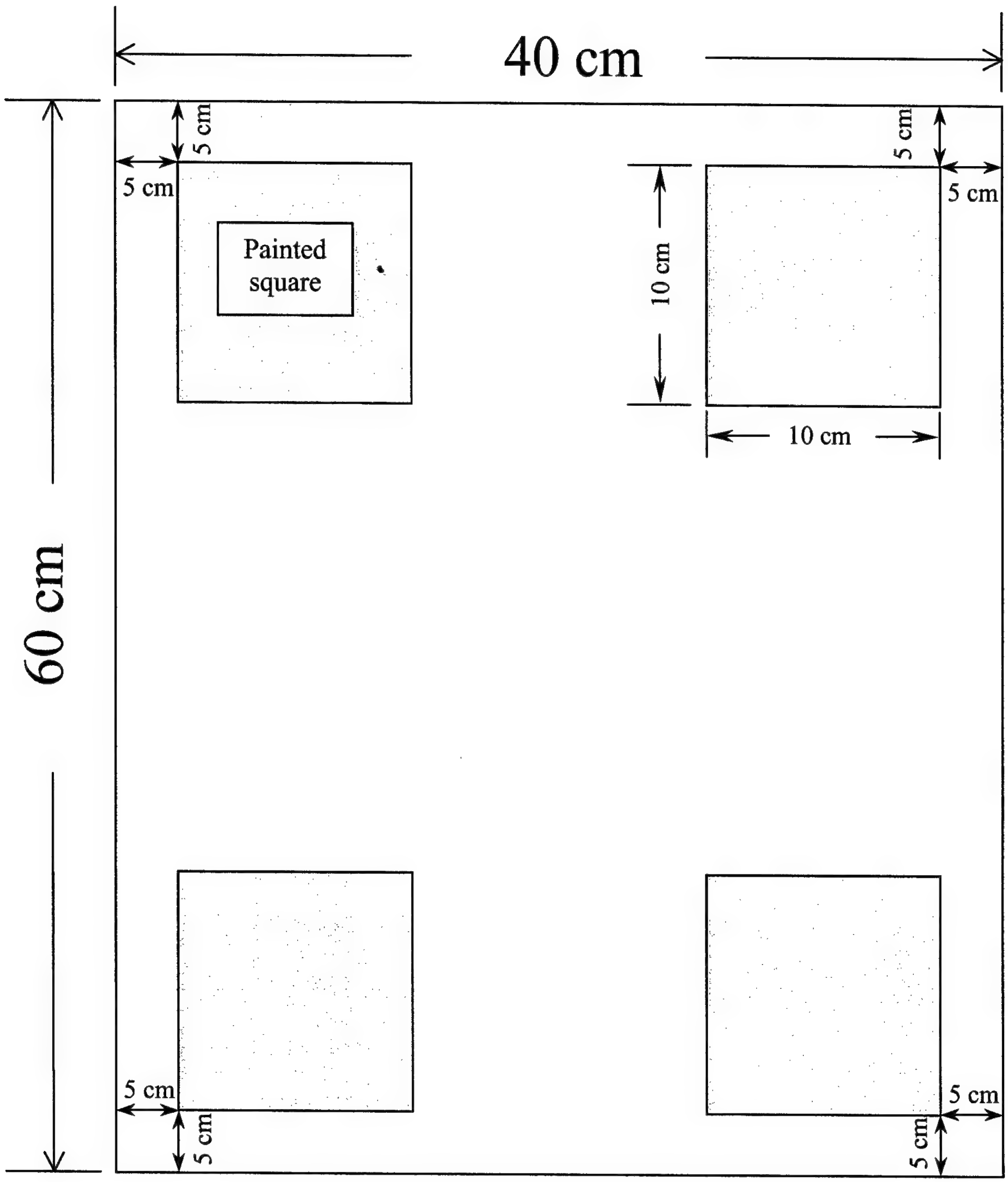
Appendix

A. Sheet metal diagram



B. Modified Borg Scale

After completing an experimental condition, subjects were asked to evaluate their grip-strength and the force needed (i.e. scraping force) to perform the removal task. The following Modified Borg Scale was used for both of these self-assessments.

Force Evaluation

0 - Nothing at all

0.5 - Very, very easy

1 - Very easy

2 - Easy

3 - Moderately Hard

4 - Somewhat Hard

5 - Hard

6

7 - Very Hard

8

9

10 - Very, Very Hard

C. Plastic Scraper Exertion Summary

Subject	Trial	Glove 1	Glove 2	Glove 3	Glove 4	Glove 5	Glove 6	Glove 7	Glove 8	Glove 9	Glove 10	Glove 11	Glove 12	Glove 13
1	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	3:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
2	1	2:3	2:3	2:3	3:3	2:3	2:3	2:4	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:4	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
3	1	2:3	2:3	2:3	2:3	2:4	2:3	2:3	2:3	2:3	2:3	2:4	2:3	2:3
	2	2:2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:5	2:3
4	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
5	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
6	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	1:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
7	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
8	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
9	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	2:3	2:3	2:4	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3

Note: Data are presented as (impulse used):(total number of removal impulses).

D. Nylon Pad Exertion Summary

Sub. #	Trial	Glove 1	Glove 2	Glove 3	Glove 4	Glove 5	Glove 6	Glove 7	Glove 8	Glove 9	Glove 10	Glove 11	Glove 12	Glove 13
1	1	4,11,19:21	4,14,21:25	4,11,19:21	3,11,19:22	3,12,19:21	3,13,20:22	4,8,11:16	3,10,19:21	3,12,20:23	4,8,16:21	3,9,13:17	2,12,21:24	4,15,20:23
	2	3,9,17:23	3,12,19:23	3,12,19:23	4,10,19:23	3,11,18:20	3,11,16:18	10,15,17:19	3,13,19:22	4,11,15:19	3,16,21:25	4,9,15:18	4,11,16:20	4,10,13:16
2	1	4,9:11	4,7:9	2,5:8	3,5:8	3,4:7	3,7:9	2,4:6	4,5:7	2,5:7	2,6:11	3,4:6	4,5:7	2,5:7
	2	3,7:8	3,6:8	2,6:7	4,8:9	3,6:7	5,9:11	2,5:8	2,5:7	2,5:6	4,6:9	3,5:7	2,3:5	4,5:7
3	1	3,4:6	2,3:4	4,5:6	2,3:4	2,4:6	4,5:6	2,6:7	2,3:4	2,4:5	2,3:4	2,4:5	3,4:5	3,5:7
	2	2,3:5	2,3:4	3,4:5	2,3:4	2,3:4	3,4:5	3,4:5	2,3:5	2,3:4	2,3:5	2,3:5	2,3:4	3,4:5
4	1	2,3:4	2:3	2,3:4	2,3:5	2:3	2,3:4	2,3:4	2,4:5	2,3:4	2,3:4	2:3	3,4:5	2,3:4
	2	2,3:4	2:3	2,3:5	2,3:4	2:3	2,3:4	2,4:5	2,3:4	2,3:4	2,3:4	2,3:4	3,4:5	2,3:4
5	1	4,7:9	3,8:9	3,4:9	3,6:9	2,7:9	3,7:9	3,6:9	3,6:9	4,8:9	2,8:9	4,7:9	4,6:9	3,8:9
	2	2,6:9	3,7:9	4,8:9	3,7:9	3,6:9	4,6:9	3,6:9	4,8:9	3,6:9	2,6:9	4,7:10	3,5:9	3,7:9
6	1	2,3:4	2:3	2,3:4	2:2	2,3:4	2:3	2,3:4	2,3:4	2:2	2,3:4	2,3:4	2,3:4	2:3
	2	2,3:4	2,3:4	2,3:4	2,3:4	2:3	2:3	2,3:4	2,3:4	2,3:4	2,3:4	2,3:4	2,3:4	2:3
7	1	2,6:7	2,5:6	4,5:7	2,3:5	4,5:7	2,4:6	3,4:5	3,5:6	2,4:5	2,3:5	3,5:6	2,6:8	2,4:5
	2	2,5:6	3,5:6	2,4:6	2,4:5	4,7:8	2,3:5	2,4:5	2,4:7	3,5:6	2,5:6	2,3:4	2,5:6	2,4:7
8	1	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
	2	2:3	2:3	3:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3	2:3
9	1	3,4:7	2,4:6	3,5:7	3,7:8	3,6:8	2,3:5	3,7:9	3,4:6	3,5:7	2,5,8:10	2,6:8	2,5:7	2,5:9
	2	2,4:6	3,4:6	3,5:7	4,5:7	3,5:6	3,4:6	3,6,9:10	2,3:5	2,3:7	3,5:7	2,6,9:10	3,6:8	4,6:7

Note: Data are presented as (impulse(s) used):(total number of removal impulses).

E. Post Hoc Analyses

E-1. Glove Effect on Plastic Scraper Removal Forces

Glove	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}
	8.873281	*9.785259*	*10.89144*	*11.98206*	*10.90902*	*9.500222*	*9.732608*	*8.882601*	*9.348230*	*9.697012*	*11.97334*	*9.845887*	*9.891032*
1		0.42362	0.07879	**0.00748**	0.07627	0.58189	0.45077	0.99346	0.67646	0.46969	**0.00764**	0.39358	0.37210
2	0.42362		0.33220	0.05612	0.32462	0.80218	0.96308	0.42835	0.70097	0.93817	0.05708	0.95750	0.92592
3	0.07879	0.33220		0.33901	0.98767	0.22339	0.30984	0.08016	0.17727	0.29530	0.34287	0.35924	0.38026
4	**0.00748**	0.05612	0.33901		0.34681	**0.03143**	0.05060	**0.00766**	**0.02264**	**0.04713**	0.99388	0.06310	0.06876
5	0.07627	0.32462	0.98767	0.34681		0.21764	0.30260	0.07760	0.17243	0.28830	0.35073	0.35126	0.37199
6	0.58189	0.80218	0.22339	**0.03143**	0.21764		0.83815	0.58750	0.89371	0.86267	**0.03201**	0.76129	0.73127
7	0.45077	0.96308	0.30984	0.05060	0.30260	0.83815		0.45568	0.73553	0.97504	0.05148	0.92068	0.88925
8	0.99346	0.42835	0.08016	**0.00766**	0.07760	0.58750	0.45568		0.68245	0.47471	**0.00782**	0.39811	0.37647
9	0.67646	0.70097	0.17727	**0.02264**	0.17243	0.89371	0.73553	0.68245		0.75921	**0.02308**	0.66195	0.63348
10	0.46969	0.93817	0.29530	**0.04713**	0.28830	0.86267	0.97504	0.47471	0.75921		**0.04796**	0.89588	0.86458
11	**0.00764**	0.05708	0.34287	0.99388	0.35073	**0.03201**	0.05148	**0.00782**	**0.02308**	**0.04796**		0.06416	0.06990
12	0.39358	0.95750	0.35924	0.06310	0.35126	0.76129	0.92068	0.39811	0.66195	0.89588	0.06416		0.96834
13	0.37210	0.92592	0.38026	0.06876	0.37199	0.73127	0.88925	0.37647	0.63348	0.86458	0.06990	0.96834	

E-2. Glove Effect on Nylon Pad Removal Forces

Glove	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}
	22.09380	*24.61775*	*23.94905*	*25.59805*	*24.06991*	*27.55418*	*27.41887*	*25.34151*	*27.27757*	*23.15355*	*26.10208*	*26.82723*	*29.11949*
1		0.13505	0.27069	**0.03903**	0.24091	**0.00154**	**0.00198**	0.05539	**0.00258**	0.52835	**0.01863**	**0.00573**	**0.00006**
2	0.13505		0.69055	0.55967	0.74427	0.08271	0.09765	0.66657	0.11551	0.38411	0.37764	0.19018	**0.00847**
3	0.27069	0.69055		0.32725	0.94261	**0.03384**	**0.04095**	0.40775	**0.04970**	0.63585	0.20165	**0.08889**	**0.00264**
4	**0.03903**	0.55967	0.32725		0.36378	0.24566	0.27963	0.87857	0.31842	0.14763	0.76408	0.46474	**0.03810**
5	0.24091	0.74427	0.94261	0.36378		**0.04013**	**0.04835**	0.44952	**0.05841**	0.58551	0.22792	0.10293	**0.00328**
6	**0.00154**	0.08271	**0.03384**	0.24566	**0.04013**		0.93577	0.18955	0.86915	**0.01001**	0.38804	0.66519	0.35228
7	**0.00198**	0.09765	**0.04095**	0.27963	**0.04835**	0.93577		0.21782	0.93294	**0.01245**	0.43362	0.72464	0.31241
8	0.05539	0.66657	0.40775	0.87857	0.44952	0.18955	0.21782		0.25051	0.19449	0.65073	0.37720	**0.02634**
9	**0.00258**	0.11551	**0.04970**	0.31842	0.05841	0.86915	0.93294	0.25051		**0.01557**	0.48442	0.78857	0.27413
10	0.52835	0.38411	0.63585	0.14763	0.58551	**0.01001**	**0.01245**	0.19449	**0.01557**		0.08147	**0.03067**	**0.00057**
11	**0.01863**	0.37764	0.20165	0.76408	0.22792	0.38804	0.43362	0.65073	0.48442	0.08147		0.66597	**0.07471**
12	**0.00573**	0.19018	0.08889	0.46474	0.10293	0.66519	0.72464	0.37720	0.78857	**0.03067**	0.66597		0.17425
13	**0.00006**	**0.00847**	**0.00264**	**0.03810**	**0.00328**	0.35228	0.31241	**0.02634**	0.27413	**0.00057**	0.07471	0.17425	

E-3. Glove Effect on Static Finger Flexor EMG Percent of Maximum

Glove	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}
	9.996402	12.26193	13.24318	15.59525	12.17090	11.74662	14.60111	14.53841	12.71488	11.77342	13.41750	13.79612	14.43438
1		0.10200	**0.02051**	**0.00012**	0.11620	0.20445	**0.00130**	**0.00149**	0.05085	0.19769	**0.01487**	**0.00715**	**0.00188**
2	0.10200		0.47477	**0.01751**	0.94702	0.70696	0.09157	0.10039	0.74103	0.72153	0.40033	0.26525	0.11654
3	**0.02051**	0.47477		0.08984	0.43496	0.27703	0.32355	0.34621	0.69994	0.28564	0.89875	0.68669	0.38605
4	**0.00012**	**0.01751**	0.08984		**0.01478**	**0.00648**	0.46901	0.44157	**0.03892**	**0.00684**	0.11567	0.19225	0.39819
5	0.11620	0.94702	0.43496	**0.01478**		0.75688	0.07991	0.08780	0.69149	0.77178	0.36449	0.23822	0.10230
6	0.20445	0.70696	0.27703	**0.00648**	0.75688		**0.04064**	**0.04510**	0.48061	0.98439	0.22544	0.13826	0.05344
7	**0.00130**	0.09157	0.32355	0.46901	0.07991	**0.04064**		0.96349	0.17190	**0.04250**	0.38907	0.55736	0.90314
8	**0.00149**	0.10039	0.34621	0.44157	0.08780	**0.04510**	0.96349		0.18638	**0.04714**	0.41453	0.58838	0.93947
9	0.05085	0.74103	0.69994	**0.03892**	0.69149	0.48061	0.17190	0.18638		0.49279	0.60842	0.43116	0.21240
10	0.19769	0.72153	0.28564	**0.00684**	0.77178	0.98439	**0.04250**	**0.04714**	0.49279		0.23288	0.14340	0.05579
11	**0.01487**	0.40033	0.89875	0.11567	0.36449	0.22544	0.38907	0.41453	0.60842	0.23288		0.78233	0.45895
12	**0.00715**	0.26525	0.68669	0.19225	0.23822	0.13826	0.55736	0.58838	0.43116	0.14340	0.78233		0.64158
13	**0.00188**	0.11654	0.38605	0.39819	0.10230	0.05344	0.90314	0.93947	0.21240	0.05579	0.45895	0.64158	

E-4. Glove Effect on Dynamic Finger Flexor EMG Percent of Maximum

Glove	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}	{10}	{11}	{12}	{13}
	16.63443	*19.40564*	*19.50521*	*22.14958*	*19.74866*	*19.99254*	*22.37494*	*20.05636*	*19.63469*	*18.72753*	*22.47372*	*20.79592*	*22.02534*
1		0.09707	0.08590	**0.00138**	0.06302	**0.04549**	**0.00091**	**0.04167**	0.07299	0.20788	**0.00075**	**0.01400**	**0.00174**
2	0.09707		0.95191	0.10033	0.83543	0.72236	0.07592	0.69365	0.88966	0.68147	**0.06691**	0.40111	0.11632
3	0.08590	0.95191		0.11299	0.88278	0.76793	0.08601	0.73861	0.93749	0.63791	0.07600	0.43550	0.13056
4	**0.00138**	0.10033	0.11299		0.14941	0.19451	0.89143	0.20786	0.13135	**0.04167**	0.84437	0.41356	0.94001
5	0.06302	0.83543	0.88278	0.14941		0.88257	0.11542	0.85217	0.94496	0.53688	0.10263	0.52655	0.17124
6	**0.04549**	0.72236	0.76793	0.19451	0.88257		0.15251	0.96916	0.82843	0.44465	0.13650	0.62687	0.22111
7	**0.00091**	0.07592	0.08601	0.89143	0.11542	0.15251		0.16362	0.10077	**0.03031**	0.95229	0.34068	0.83232
8	**0.04167**	0.69365	0.73861	0.20786	0.85217	0.96916	0.16362		0.79846	0.42213	0.14669	0.65445	0.23577
9	0.07299	0.88966	0.93749	0.13135	0.94496	0.82843	0.10077	0.79846		0.58315	0.08934	0.48272	0.15112
10	0.20788	0.68147	0.63791	**0.04167**	0.53688	0.44465	**0.03031**	0.42213	0.58315		**0.02626**	0.21323	**0.04938**
11	**0.00075**	0.06691	0.07600	0.84437	0.10263	0.13650	0.95229	0.14669	0.08934	**0.02626**		0.31158	0.78600
12	**0.01400**	0.40111	0.43550	0.41356	0.52655	0.62687	0.34068	0.65445	0.48272	0.21323	0.31158		0.45750
13	**0.00174**	0.11632	0.13056	0.94001	0.17124	0.22111	0.83232	0.23577	0.15112	**0.04938**	0.78600	0.45750	

EDUCATION PLAN AND FINANCIAL VOUCHER (Cover Sheet)	PAGE 1 OF 3 PAGES

PRIVACY ACT STATEMENT

AUTHORITY: 10 U.S.C. 8012.

PRINCIPAL PURPOSE: Recording of academic schedule to meet AF educational requirements. SSN needed to positively identify student.

ROUTINE USES: Serves as a source document for authorizing tuition payments to civilian institutions. Guides students in arrangement of education programs to meet AF education requirements and completion of program in minimum possible time.

DISCLOSURE: Voluntary; however failure to comply would place student in violation of AFIT directive and result in dismissal from program.

NOTICE: This form is used as a source document for committing government money to the educational institutions of AFIT-funded students. Any changes to an approved plan must be coordinated with the appropriate AFIT program manager.

( ) INITIAL ED PLAN ( ) REVISED ED PLAN (•) FINAL ED PLAN

NAME OF EDUCATIONAL INSTITUTION	MAJOR	COMPLETION DATE	DEGREE
UNIVERSITY OF CALIFORNIA AT DAVIS	ALL SCI-BAS BIO-BIO ENGINER	6/5/2002	MS

NAME *(Grade, Last Name, First Name, MI, Present Mailing Address & Zip Code).*		FOR USE BY PROGRAM MANAGER ONLY
CAPT RYBCZYNSKI IAN C. 114 JALISCO DAVIS CA 95616		
SERVICE NUMBER (SSN) 600264552	TELEPHONE NUMBER (530) 758-4520	

PRINTED/TYPED NAME AND SIGNATURE OF ADVISOR *(Not required on final ed plan)*	TELEPHONE NUMBER	COMPLETION DATE	AFSC
Fadi Fathallah	(530)752-1612		43E3
	DATE	PGM MGR'S SIGNATURE	DATE

TITLE OF ( ) DISSERTATION (•) THESIS ( ) MAJOR REPORT

Ergonomic Impact of Glove Use in a Coating Removal Task

CERTIFICATION Required in Final Education Plan Only	
I hereby certify that I expended, during my entire assignment with AFIT, a total of $750.00 for Books and Supplies and a total of $325.00 for Research Project Preparation. [x] I completed degree requirements and did/will officially receive the degree of MS - Biomedical Engineering on 13 Jun 02(date). [x] An official transcript [([x]) with degree posted] has been ordered and should arrive by 15 Aug 02. [ ] I plan to complete degree requirements in absentia by (date).	36 Credits Required for Degree 0 Accepted Transfer Credits 36 Credits Needed 36 Credits on This Plan Which Count Toward Degree Requirements

STUDENT'S SIGNATURE	DATE
	6/10/2002

AFIT Form 18

EDUCATION PLAN AND FINANCIAL VOUCHER
(Continuation Sheet)

PM APPROVAL	COUNTING FM 18 THIS IS PAGE 2 OF 3

LAST NAME	SCHOOL NAME	SSN	DATE
RYBCZYNSKI	UNIVERSITY OF CALIFORNIA AT DAVIS	600264552	6/10/2002

TERMS LISTED ARE: ○ SEMESTER ● QUARTER ○ TRIMESTER ○ ACADEMIC YEAR

TERM 1 DATES 9/28/2000 TO 12/15/2000

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
1	BIM228	Skeletal Muscle Mechanics	4	A
1	BIM202	Molecular and Cellular Biology	4	A
2	BIM241	Introduction to MRI	3	A
1	BIM290	Biomedical Engineering Seminar (Required to take every quart	1	S
		Term GPA: Cum GPA:	Total: 12	

TERM 2 DATES 1/2/2001 TO 3/23/2001

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
1	BIM227	Research Techniques in Biomechanics	4	A
1	EME151	Probabilistic Systems Analysis for Engineers	3	B+
2	BIM290C	Grad Research Conference (Ergonomic Evaluation Too	1	S
2	BIM299	Biomedical Research (Ergonomic Evaluation Tools Re	1	S
1	BIM290	Biomedical Engineering Seminar	1	S
2	EBS289C	Biological Engineering	2	A
		Term GPA: Cum GPA:	Total: 12	

TERM 3 DATES 3/28/2001 TO 6/15/2001

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
2	EBS289L	Biological Systems Engineering - Ergonomics	3	A
2	EBS128	Biomechanics and Ergonomics	4	A
2	EXS111	Environmental Effects on Physical Performance	3	A
1	BIM290	Biomedical Engineering Seminar	1	S
		Term GPA: Cum GPA:	Total: 11	

TERM 4 DATES 9/24/2001 TO 12/15/2001

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
2	CHE118A	Organic Chemistry	4	A
2	EXS115	Biomechanical Bases of Movement	3	A
1	BIM290	Biomedical Engineering Seminar	1	S
1	BIM299	Biomedical Research - Data Collection	4	S
		Term GPA: Cum GPA:	Total: 12	

TERM 5 DATES 1/2/2002 TO 3/23/2002

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
1	BIM299	Biomedical Research - Initial Draft	11	T
1	BIM290	Biomedical Engineering Seminar	1	
		Term GPA: Cum GPA:	Total: 12	

AFIT Form 18A

EDUCATION PLAN AND FINANCIAL VOUCHER
(Continuation Sheet)

PM APPROVAL	COUNTING FM 18 THIS IS PAGE 3 OF 3

LAST NAME	SCHOOL NAME	SSN	DATE
RYBCZYNSKI	UNIVERSITY OF CALIFORNIA AT DAVIS	600264552	6/10/2002

TERMS LISTED ARE: ○ SEMESTER ◉ QUARTER ○ TRIMESTER ○ ACADEMIC YEAR

TERM 6 DATES **3/28/2002 TO 6/14/2002**

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
1	BIM299	Biomedical Research - Completion/Submission	11	T
1	BIM290	Biomedical Seminar	1	
		Term GPA: Cum GPA:	Total: 12	

TERM 7 DATES TO

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
				T
		Term GPA: Cum GPA:	Total: 0	

TERM 8 DATES TO

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
				T
		Term GPA: Cum GPA:	Total: 0	

TERM 9 DATES TO

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
				T
		Term GPA: Cum GPA:	Total: 0	

TERM 10 DATES TO

*	Dept & Course No.	Complete Course Title	Credit Hours	Grade
				T
		Term GPA: Cum GPA:	Total: 0	

AFIT Form 18A